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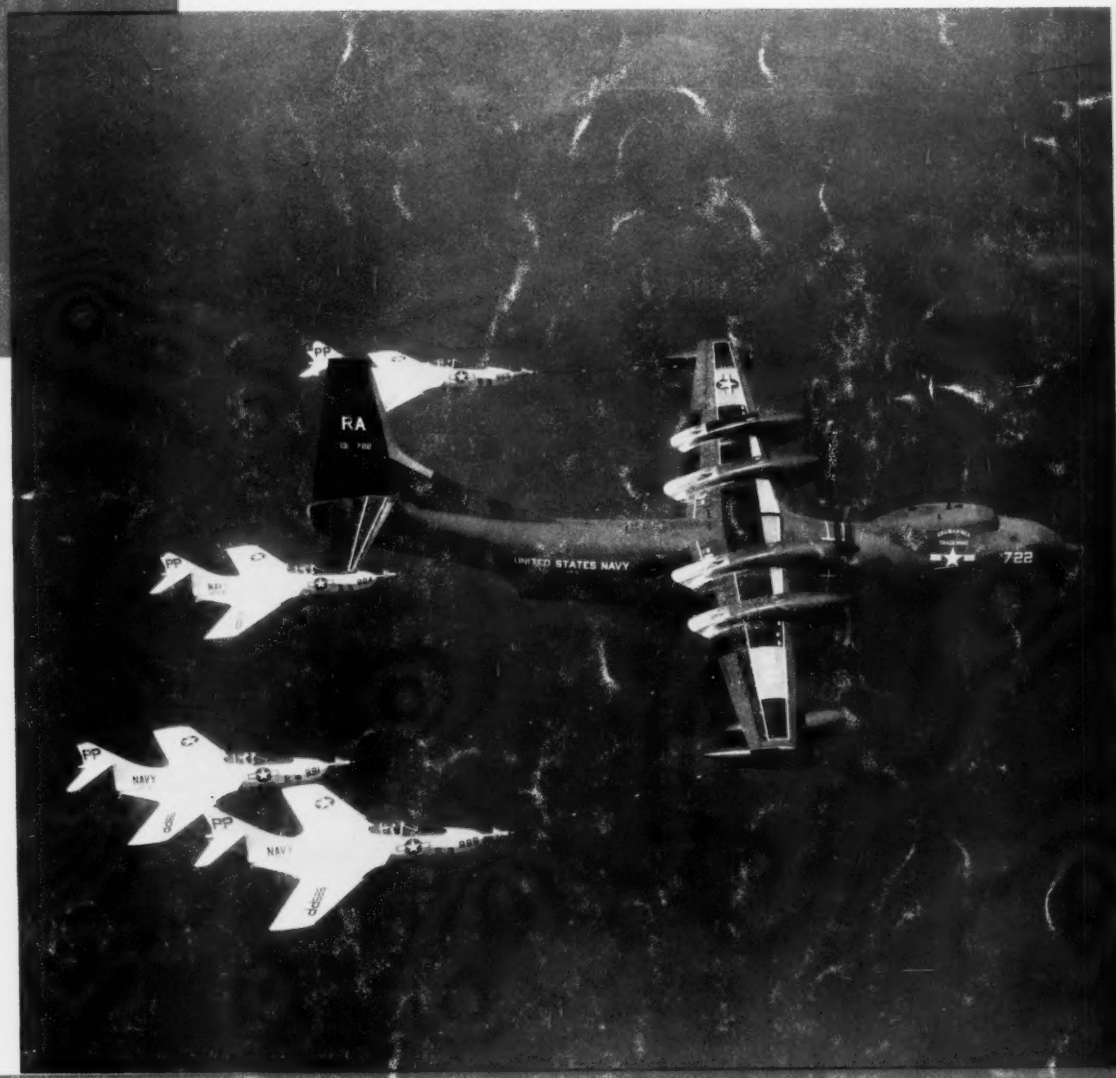
# Aeronautical Engineering REVIEW

INSTITUTE OF THE AERONAUTICAL SCIENCES

1932 25th ANNIVERSARY 1957

AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT




research • design • construction • testing • operation

## *For Naval Aviation—A Bright Future*

by The Honorable Thomas Gates, Jr.

**October, 1957**

# ARMA'S SECRET WEAPON

Bug hunting . . . failure testing . . . safety factors . . . flight testing—none of these traditional reliability concepts is sufficient to insure maximum performance of missile guidance systems.

We use them all at Arma—but the designer's pencil is our "secret weapon." For true reliability must originate at the design stage—and then be implemented by a full-scale quality control and reliability program. ARMA . . . Garden City, N. Y. A division of American Bosch Arma Corporation.

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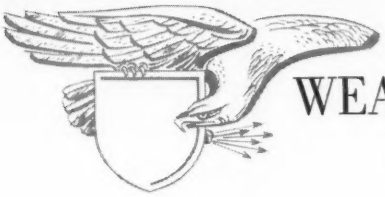
# What does it take to create a complete

# Missile Weapon System?

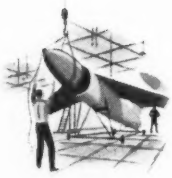


## WEAPON SYSTEM: A definition

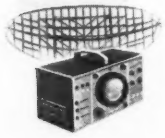
*"A system composed of equipment, skills and techniques, the composite of which forms an instrument of combat, usually . . . having an air vehicle as its major operational element. The complete weapon system includes all related equipment, materials, services, and personnel required solely for the operation of the air vehicle . . . so that the instrument of combat becomes a self-sufficient unit of striking power within its intended operational environment."*

*– Quoted from Defense Department Regulations*

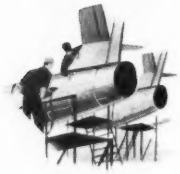
**GUIDANCE**
– of the accuracy of ATRAN. Goodyear Aircraft Corporation designed, developed and produces this system for guiding American missiles.



**RADOMES**
– exterior structural plastic housing for a missile's electronic eyes. Goodyear Aircraft is a pioneer and leading producer of such housings.



**RADAR**
– Goodyear Aircraft builds hi-performance airborne systems and large radar structures for early warning, missile guidance and tracking systems.



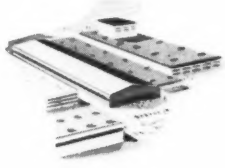
**AIRFRAMES**
– fabricated of the newest alloys by the most advanced techniques. Goodyear Aircraft has decades of light-metals experience in airship pioneering, building thousands of complete airplanes and structures for today's jet aircraft and missiles.

**ROCKETS**
–to propel the missiles skyward. Goodyear Aircraft builds more large-size rocket cases than any other manufacturer, has one of the largest facilities in the nation.

**GROUND SUPPORT EQUIPMENT**
– to check the missile's design characteristics, the complete system's performance–to move, maintain, launch a squadron's missiles. Goodyear Aircraft designs and builds this equipment, and has created today's foremost mobile missile ground support system.

**COMPUTERS AND FLIGHT SIMULATORS**
– to check the missile's initial design characteristics and simulate its flight. Goodyear Aircraft builds GEDA, an analog computer, and supplies flight simulators for the military services.

**UNIFIED ENGINEERING**
– to solve the technical complexities of creating a complete system. Goodyear Aircraft has a Weapon System Engineering organization–specialists with a unified approach to, and complete familiarity with, the total problem.



**PRODUCTION FACILITIES**
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# Aeronautical Engineering Review

Vol. 16—No. 10 October, 1957


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*Official U.S. Navy photo*

**Cover**—R3Y "Tradewinds" refuels four F9F Navy fighters simultaneously in demonstration before delegates to the National Naval Aviation Meeting in San Diego. (For more information on the Naval meeting see pp. 36–43.)


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A-286 was developed in the A-L Research Laboratory in Watervliet, N.Y., in the 1949-51 period. Among the high-strength, heat-resisting alloys, it has exceptionally low strategic alloy content, improved hot-working and machining qualities, and good center ductility in large sections. Currently used in jet engines and superchargers for such applications as turbine wheels and blades, frames, casings, afterburner parts, bolting, etc.

This alloy is readily produced in large quantities without the need of special steel-making equipment. It is available in the form of billets, bars, forgings, sheet, strip, tubing and hot-extruded shapes.

**ALTEMP S-816** . . . a chromium-nickel-cobalt base alloy, strengthened by additions of molybdenum and tungsten, and with a columbium-carbon ratio of ten to one to insure its structural stability. Designed for high strength and corrosion-resistance service in the 1200-1500 F range, and at higher temperatures under lower stress conditions. Developed in the A-L Research Laboratory at Watervliet, N.Y. in the years of 1940-43, and engine-tested and proved for periods of over 30,000 hours.

S-816 is used currently for turbine blades in two of the production jet engines, also in a number of experimental aircraft and commercial gas turbines. Except for seamless drawn tubing, it is available in practically all forms and shapes in which stainless steels are processed, including hot extrusions.

**ALTEMP S-590** was designed for service in the range of 1100-1400 F temperatures where high strength and corrosion resistance are required, and where cost is also a factor. Unlike S-816, which is practically a non-ferrous alloy, S-590 has a chromium-nickel-cobalt-iron base. However, it employs the same molybdenum and tungsten additives, and the same columbium-carbon ratio.

S-590 was developed at the Watervliet Laboratory and field-proved during the same years as S-816. It is available in the same shapes and forms, and is currently being used for turbine blades and wheels in experimental commercial gas turbines.

**OTHER GRADES** . . . among the many other Super Alloys made by Allegheny Ludlum are V-36, M-252, 19-9 DL, 19-9 DX and Waspaloy.

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# Royal Swedish Navy Orders Vertol 44's

A special committee of the Swedish Navy made a year-long study of helicopters suitable for anti-submarine warfare as well as utility transportation. In the United States they consulted with headquarters personnel of the three armed services, visited helicopter manufacturers and toured military operating units.

At the conclusion of this intensive study, the Swedish Navy placed an initial order for four of the 22-place Vertol 44's, to be augmented later by additional procurement.

Official Navy announcement of the purchase said the choice was mainly based upon the Vertol 44's "good stability in hovering and towing missions, good instrument flight capabilities and mission endurance . . . practically unlimited controllability for the contemplated missions."

Sweden thus became the fifth western nation to purchase the sturdy Work Horse helicopter, first choice of the experts for the most difficult assignments.

In commercial or military use the Vertol 44 offers these features:

- Highest useful load, largest seating capacity
- Lowest seat mile cost
- Automatic stabilization
- Instrument flight capability

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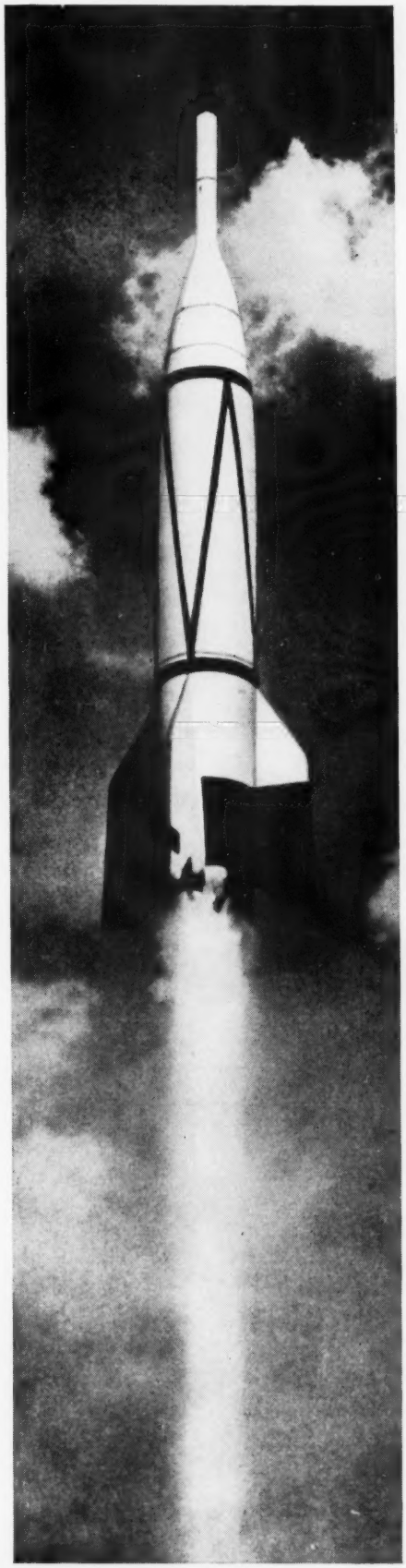
Lunar craters as seen through an astronomical telescope.
The puzzle of what's on the other side may soon be answered.

# World's oldest mystery soon to be solved

Ever since man has had the imagination to ponder *any* problem, he has wondered what lay on the dark side of the moon . . .

Now, engineers predict that rockets carrying cameras or TV will circle Luna within five years and show us her other face.

At Douglas Aircraft, where one of the first rocket and missile projects was set up in 1941, practical investigations have helped show the way to lunar circumnavigation. They have led to more effective missile guidance systems . . . helped establish basic principles of air-to-air rocket fire . . . led to use of such heat-resistant materials as titanium, ceramics, and plastics. Douglas engineers have investigated *space physiology and psychology*—how man will react in the weightfree glare of space—and even investigated new kinds of power, engines that may use ions or light rays to reach the stars.



Wac-Corporal, an early Douglas rocket, takes off in the nose of a captured V-2 to set what was then a world altitude record. Douglas has since developed such weapons as *Nike*, the new *Nike-Hercules*, and the Army's potent *Honest John*, which can carry a nuclear warhead. Even more exciting projects—still classified—are going full speed ahead at Douglas.

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# GRUMMAN

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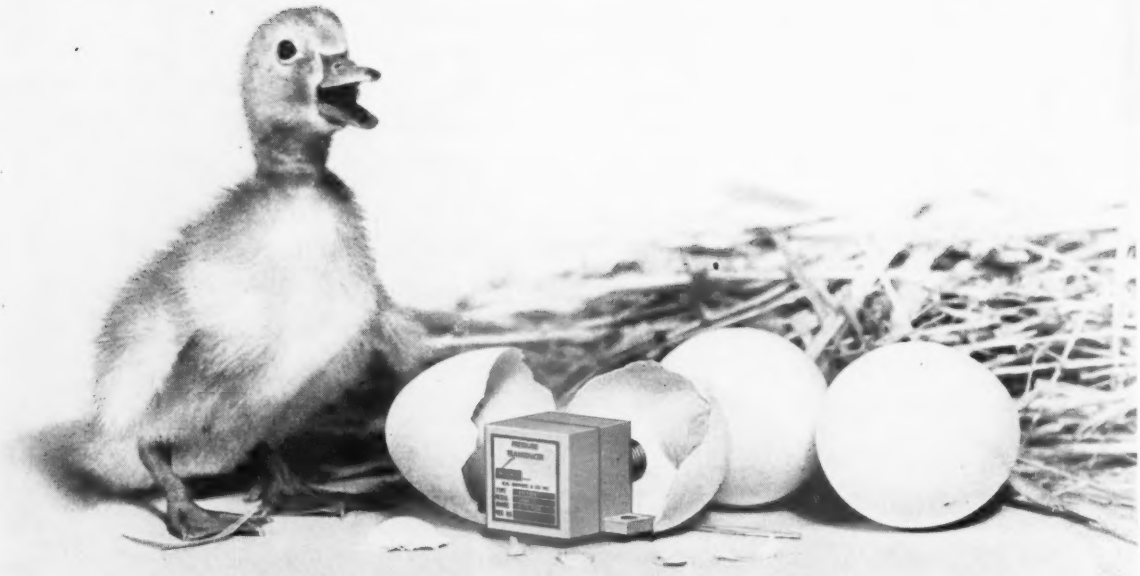
*...Giannini has really hatched one this time.*



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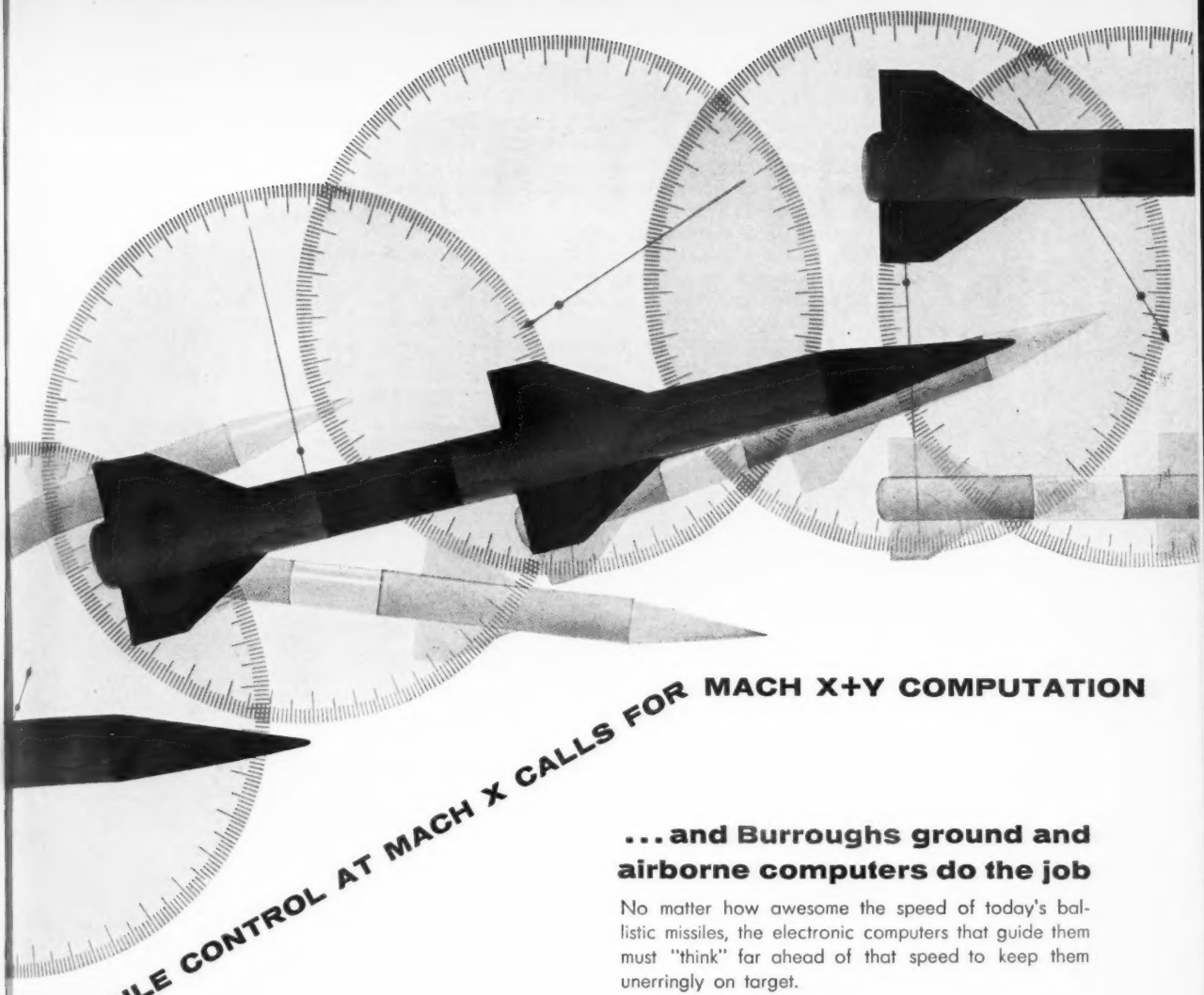

# MISSILE CONTROL AT MACH X CALLS FOR MACH X+Y COMPUTATION

## ...and Burroughs ground and airborne computers do the job

No matter how awesome the speed of today's ballistic missiles, the electronic computers that guide them must "think" far ahead of that speed to keep them unerringly on target.

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## MISSILE SYSTEMS THERMODYNAMICS

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*Aerothermodynamic Staff members discuss heat flux during reentry of a hypersonic vehicle. Left to right: J. I. Osborne, aerodynamics; R. G. Wilson, thermodynamic research; W. E. Brandt, thermodynamic analysis; Dr. L. H. Wilson, Thermodynamic Section head.*

*Lockheed* MISSILE SYSTEMS

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## Fenwal Units Detect Real Danger at Once

ASHLAND, MASS. — Every time a Fenwal Unit Fire and Over-Heat Detector gives an alarm, a temperature danger point has been reached that very instant. The unit will not, if properly installed, ground planes with false alarms.

A glance at the design of the Detectors will show why their response to temperature conditions is inevitably prompt and accurate. The stainless-steel shell of each Detector is the temperature-sensitive element. As it expands, it closes contacts hermetically sealed inside.

Shock and vibration cannot disturb the Detectors' accuracy. Neither can temperatures ranging from −85° F to (for short periods) 2000° F.

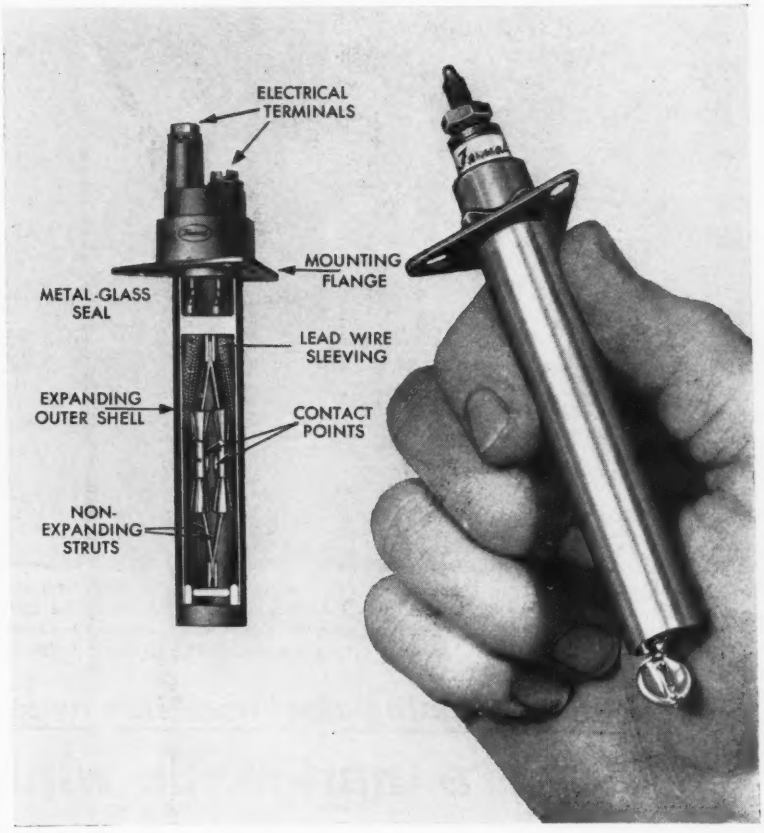
The alarm point is set at any point from 100° F to 1000° F, depending on the model. Some are factory set, others may be adjusted in the field. When temperatures drop below the alarm point, the units automatically reset themselves.

They are designed specifically for aircraft, are both light and compact. Roughly, they are slightly larger than a fountain pen, and the heaviest of them weighs only 3.25 ounces. They are generally equipped with a triangular mounting flange, calling for three holes in a 1.25-inch-diameter bolt circle.

Their current rating is 2 amps, 28 volts, D.C., and there is no need for external relays or costly field adjustment.

They may be had for either single- or double-wire circuits. Each Detector in a system operates independently. Double-terminal Detectors in a double-loop circuit eliminate all possibility of false alarms due to grounding and will operate even with a system fault. Faults in either type of circuit can be detected easily by means of a simple, push-button test.

Fenwal Unit Fire and Over-Heat Detectors meet exacting government specifications. Over many years and with hundreds of thousands of flight hours, they have been thoroughly proven by nearly every major aircraft user and manufacturer. For further details, write to **Fenwal Incorporated, Aviation Products Division, 179 Pleasant Street, Ashland, Mass.**




A TROUBLE-DETECTOR, NOT A TROUBLE-MAKER — You can depend on Fenwal Unit Fire and Over-Heat Detectors for aircraft the way you can depend on Monday's being followed by Tuesday. The reason for this dependability is made clear by the cross-section. The outer stainless-steel shell is the sensing element, and the simple moving parts are hermetically sealed inside.

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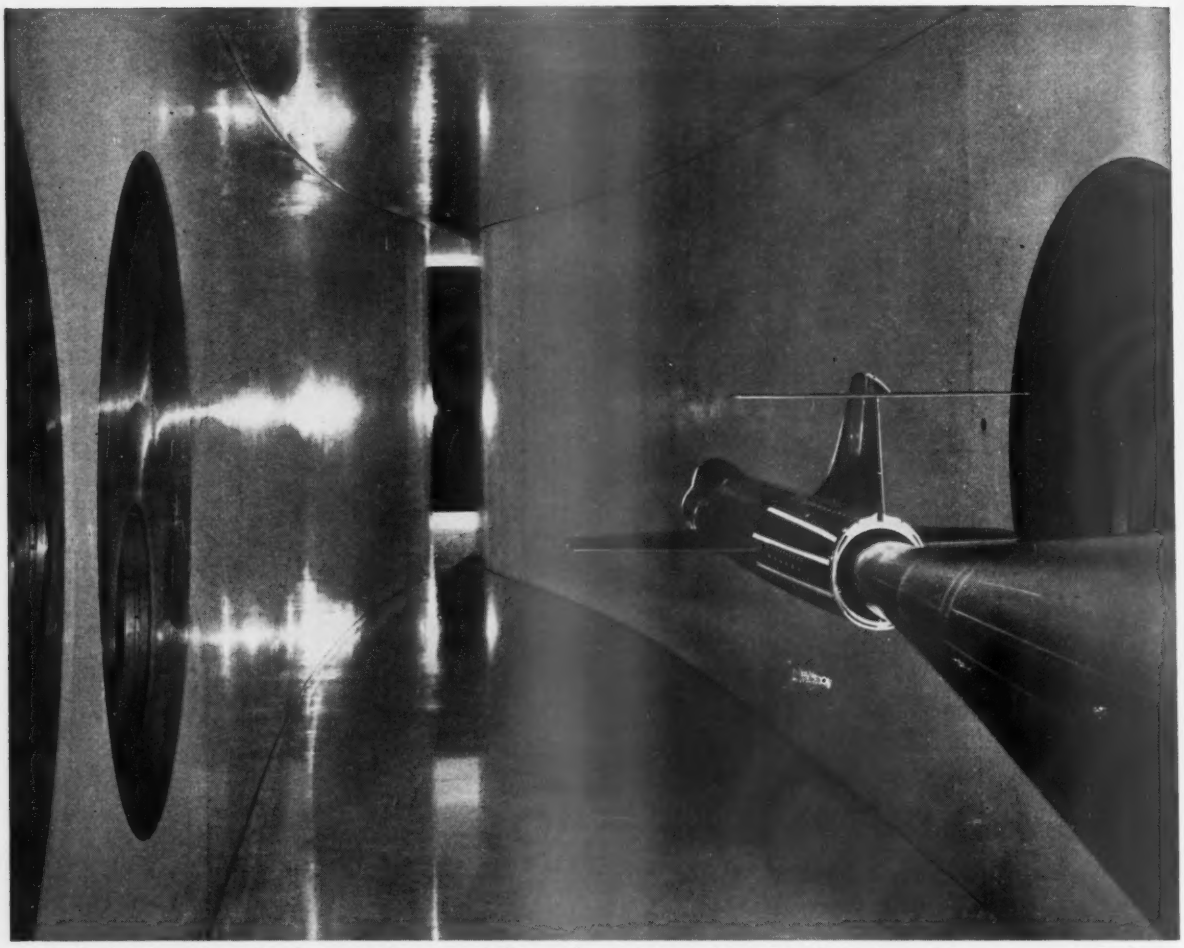

**Walls that bend** form the throat of this new wind tunnel for aeronautical research. Made of nickel-containing USS "T-1" steel, these walls can be deflected more than 10". Air speed range of this 8- by 7-foot test section is about 1650 to 2300 mph at altitude. Scale model of supersonic Lockheed F-104 fighter plane is under test by the National Advisory Committee for Aeronautics at the NACA's Ames Aeronautical Laboratory, Moffett Field, California.

***Nickel-containing steel used in new test tunnel***

# Where man-made winds whip up supersonic hurricanes

**Wind traveling 2300 mph** is just too big a blow for a conventional wind tunnel. Air can't be pushed beyond the speed of sound by power alone. The tunnel "chokes up" and generates only shock waves and more heat. To pick up an extra burst of speed, air at sonic velocity must be expanded into a larger chamber. And to get a *range* of supersonic speeds, a whole series of different sized expansion chambers is called for.

By designing *walls that bend,* a range of chamber sizes and supersonic speeds could be provided in new large wind tunnels for aircraft research. These walls had to be made of metal plates that would *"give"* without *giving in* under constant flexing and bending.

**Nickel-containing USS "T-1"** was the steel chosen for the job. Its high yield strength—almost three times greater than that of carbon steel – provides extraordinary resilience. Chamber walls of USS "T-1" can be flexed repeatedly without permanent distortion of their original shape.

**If you have a problem** involving corrosion, wear, high or low temperatures, stresses or fatigue, talk it over with us. We may be able to show you how nickel or a nickel-containing alloy can overcome your difficulties.

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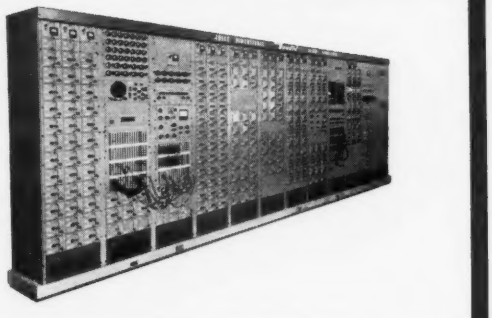
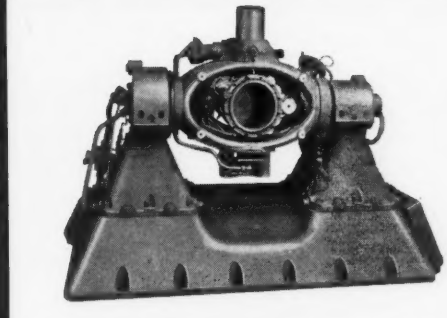
# Bendix flight simulators reduce the risks





The hazards of missile testing can be materially lowered when performance is checked out on-the-ground with a BENDIX 3-dimensional Flight Systems Simulator, prior to take-off. Comprised of two basic units—a flight table and an electronic analog computer—the BENDIX-built Flight Simulator will foretell complete operating programs from launching pad to target, for rockets, ballistic and guided missiles and jet aircraft. It catches bugs without expensive trial flights, materially reduces guesswork and adds a valuable safety factor at both ends of the test shot. *For complete technical data, mail the coupon.*

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# World's First Unmanned 'Copter

The successful maiden flight of Kaman's pilotless helicopter has added a new concept to military strategy. Flown entirely by remote control, the variety of missions possible with these ships is almost limitless. Using the Kaman robot as a flying TV or motion picture camera, complete battlefield surveillance and target marking are available without hazard to personnel. Also possible is the entry of the robot helicopter into contaminated or hazardous areas.

The control station is portable and can be operated from the ground or in air to air operations. Mission equipment such as cameras, weapons, target markers and detonators can be actuated at the control station.

Kaman is proud of this forward step which has been taken in behalf of our National Defense effort.

KAMAN

THE KAMAN AIRCRAFT CORPORATION
Bloomfield, Connecticut

THE VITAL DIFFERENCE

# These patented Fluoroflex®-T hose assemblies are truly fireproof

*Leakproof, blowoff-proof fittings contribute to optimum fire safety*

**FLUOROFLEX-T:**
***Aviation's most advanced hose***

The Original fluorocarbon hose

Patented tube compound

Greater flex life

Millions of feet in service

Over three years flying time

Superior impulse life

Leakproof, blowoff-proof fittings

Self-supporting pre-formed assemblies

Reliability of patented Fluoroflex®-T fireproof hose assemblies is assured because: 1) patented tube withstands higher temperatures than previously used materials; 2) assembly is fully protected by the special impregnated fireproof sleeving; and 3) just as vital, fittings are blowoff-proof.

Resistoflex's securely swaged couplings provide the safety factor which is the very minimum insurance that passengers and costly equipment should have for their protection. *These lines will not leak or spill fluids to cause or feed a fire.*

Years of service on all types of commercial and military aircraft have demonstrated the inherent reliability of this design.

Patented Fluoroflex-T fireproof hose assemblies are fully approved by CAA – have actually *surpassed fireproof requirements as tested by CAA.* The record speaks for itself – Fluoroflex-T hose assemblies truly insure optimum reliability for aircraft engines, frames and missiles.

**VITAL FACTS ABOUT FLUOROFLEX-T**

The core of all Fluoroflex-T assemblies is its specially compounded, patented tube. Many years of development were required to evolve and fully prove this tube, which now makes "The Vital Difference" in the plumbing of practically every modern aircraft and guided missile.

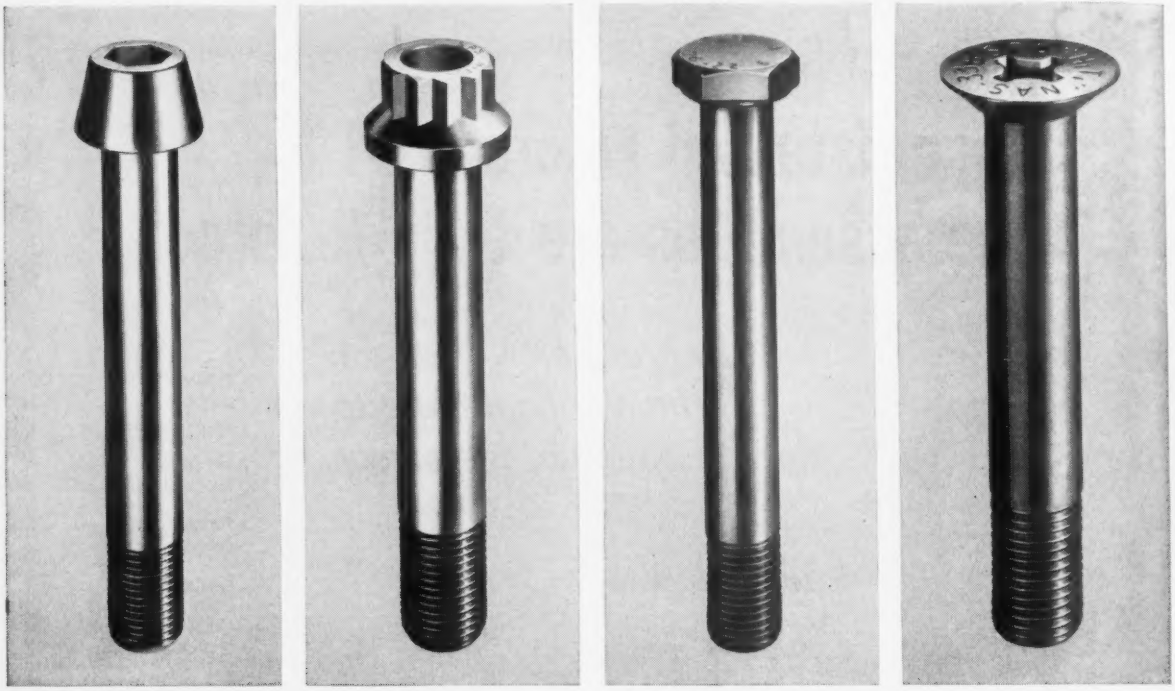
Continuous, rigid quality control methods and years of know-how guarantee the highest performance characteristics of Fluoroflex-T hose. Since the properties of products made of Teflon® can be varied greatly depending on the fabricating methods employed, the fabricator's experience and integrity remain the user's best assurance of reliability and performance. Send for data.

*® Fluoroflex is a Resistoflex trademark, reg. U.S. Pat. off. ® Teflon is a DuPont trademark.*

**Originators of high temperature fluorocarbon hose assemblies**

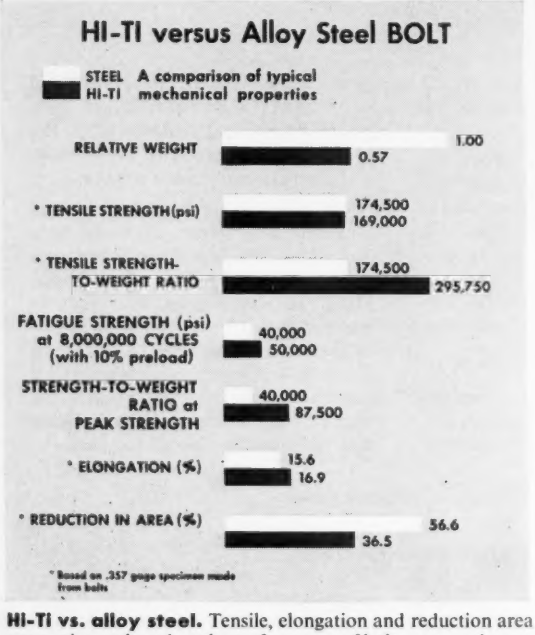
Resistoflex
CORPORATION

**Roseland, New Jersey • Western Plant: Burbank, Calif. • Southwestern Plant: Dallas, Tex.**



**SPS Hi-Ti titanium aircraft bolts** are regularly manufactured in four standard configurations: internal wrenching tension bolts, 12-point external wrenching tension bolts, hexagon head external wrenching shear bolts, and flush head internal wrenching shear bolts. Weighing 43% less than steel bolts of equivalent dimensions, they can save you as much as 1000 lb. per airframe—with no loss in strength.

# SPS Hi-Ti titanium bolts help you build lighter airframes without sacrificing strength




**Hi-Ti vs. alloy steel.** Tensile, elongation and reduction area properties are based on the performance of bolt gage specimens. Endurance limit was determined by subjecting bolts to tension load alternating between maximum and 10% preload for a total of 8,000,000 cycles without inducing failure. Significant comparison is the strength-to-weight ratio at endurance limit.

SPS Hi-Ti titanium bolts help you solve the problem of reducing airframe weight without compromising strength. They weigh 43% less than alloy steel bolts of the same size. One lb. of them can do the work of 1¾ lb. of steel bolts. Yet in tensile-strength-to-weight ratio and fatigue resistance, they outperform steel.

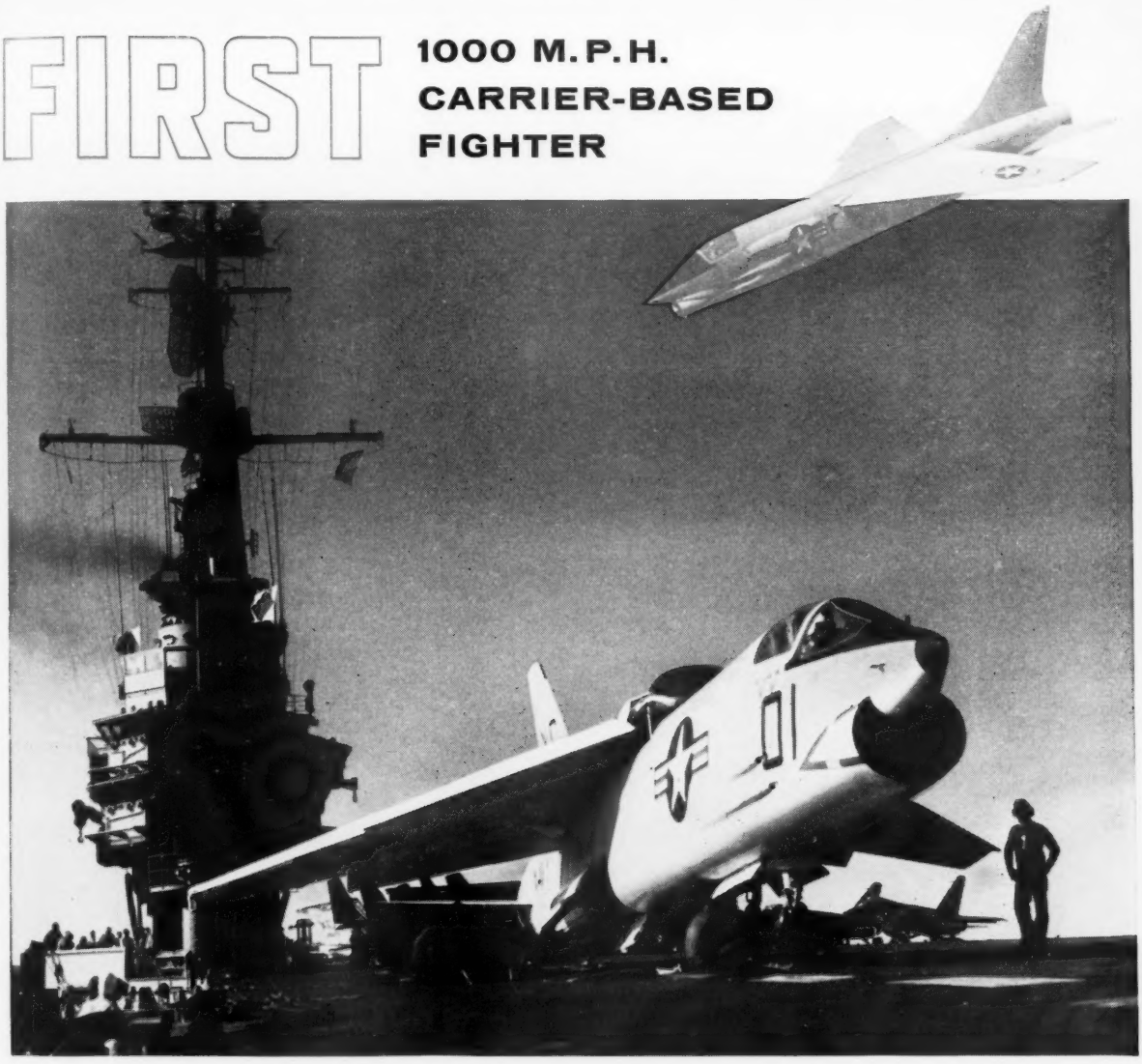
Once considered a laboratory curiosity, titanium bolts have for some time been standard production items at SPS. Hi-Ti bolts are found in many advanced design operational aircraft. This is because SPS—producer of the first successful titanium aircraft bolt—invested over $500,000 and several years of high priority research in learning how to deal with this promising but sensitive metal. Today SPS has the most extensive facilities in the industry for the production and testing of titanium fasteners. As a result, we can give you both the technical assistance and the delivery you need to utilize fully the advantages of titanium bolts in your current airframe projects.

For more information on Hi-Ti titanium aircraft bolts, write Aircraft Products Division, STANDARD PRESSED STEEL Co., Jenkintown 58, Pa.

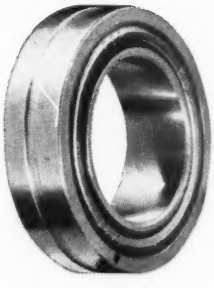
**AIRCRAFT PRODUCTS DIVISION**

STANDARD PRESSED STEEL CO.
SPS
JENKINTOWN PENNSYLVANIA

# FIRST 1000 M.P.H. CARRIER-BASED FIGHTER



## JOINS THE FLEET



Continuing a four-decade tradition of "firsts" in naval aviation, Chance Vought delivers the first 1000 plus m.p.h. aircraft for duty with the fleet—the F8U-1 Crusader.

As in most aviation firsts, Shafer Aircraft Bearing performance makes a vital contribution. In the Crusader, that performance is ample bearing capacity in higher than normal temperature ranges at key points in control systems.

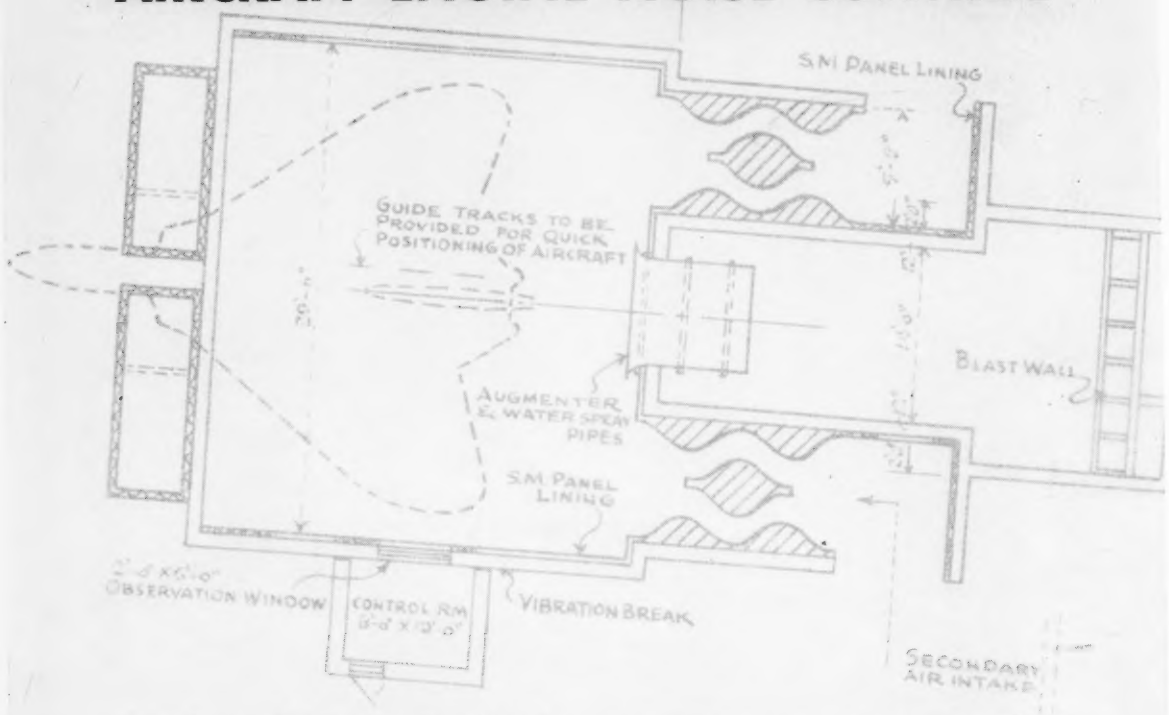
Advanced Shafer research in bearing design and materials can make an important difference in your plans for the future. Take the first step today: write for Catalog 54. Shafer Bearing Division, CHAIN Belt Company, 801 Burlington Ave., Downers Grove, Ill.

SHAFER®

BEARING DIVISION
CHAIN BELT COMPANY

# *Successful Installations*

## PROVE THAT KOPPERS LEADS IN AIRCRAFT ENGINE NOISE CONTROL




***Finest Engineering Service. Complete Line of Equipment. Unmatched Experience.***

Koppers Industrial Sound Control's experience, engineering, equipment and number of successful installations stand unchallenged in the suppression of sound for the aircraft industry.

Koppers Industrial Sound Control engineers have silenced aircraft engines of all types, in "hush houses" and with portable run-up mufflers. They have pioneered in the design of sound control equipment to solve the specific problems found in the aircraft industry. Koppers provides complete engineering service . . . including the handling of construction details for entire buildings.

Koppers Industrial Sound Control equipment is now at work suppressing noises for the aircraft industry, for other industries and in air conditioning systems. If you have a sound control problem of any kind, your wisest move is to write KOPPERS COMPANY, INC., Industrial Sound Control Dept., 5910 Scott Street, Baltimore 3, Maryland.

KOPPERS

**INDUSTRIAL SOUND CONTROL**

**Koppers Company, Inc., Metal Products Division**
**Industrial Sound Control Department**

***Engineered* Products Sold with *Service***

# PRECISE FREQUENCY CONTROL

## Robertshaw-Fulton Crystal Oven

This new compact precision Crystal Oven uses fusion temperatures of crystalline materials to provide extremely constant crystal cavity temperatures.

Completely self-contained, the unit features a continuous proportional control system which eliminates contact noise, power surges, random variations of oven temperatures, and cavity temperature drift.

### SPECIFICATIONS

**CAVITY TEMPERATURE:**
70.6°C at 24°C ambient.

**TEMPERATURE CONTROL:**
Within ±0.5°C from −20°C to +50°C ambient.
Approx. ±0.005°C at fixed ambient.

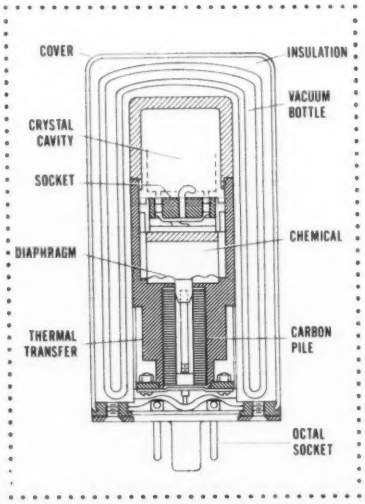
**HEATER VOLTAGE:**
5 v. a.c. or v. d.c. regulated ±2%.

**HEAT POWER:**
On warm up: approx. 5 watts
Under control: 1.6 w at TA 24°C
3.5 w at TA −20°C

**DIMENSIONS:**
2" O.D. x 4" Length.

**WEIGHT:**
Approximately 12 ounces.

**CRYSTAL HOLDER:**
Accommodates 1 HC-6/U holder.




### APPLICATIONS

Temperature control of a crystal or crystal oscillator for secondary frequency standards.

Temperature control of sensitive components, such as resistance-capacitance networks in oscillators or computer circuits.

Temperature control of zener diodes for voltage reference units in d.c. power supplies.

Constant temperature for thermocouple reference junctions.

Reference temperature for calibrating thermistors by using ovens with different cavity temperatures.

*For more information on this compact, extremely reliable Crystal Oven, send for Bulletin No. 1181-1.*

PRODUCTS FOR PROGRESS
BY THE MEN OF
AERONAUTICAL DIVISION
Robertshaw-Fulton
CONTROLS COMPANY
Santa Ana Freeway at Euclid Avenue • Anaheim, California

**OUTSTANDING FACILITIES FOR THE RESEARCH AND DEVELOPMENT OF SPECIALIZED CONTROL DEVICES**

# MIRACLE IN MINIATURE

Observation and control of amphibious and airborne landings.

Close observation of jet or piston engine test performance.

Surveillance of assembly areas and movements of forces.

Observation of danger areas, where exposure would involve danger to personnel.

**Brand new! RCA "Telemite" (model JTV-1) a 1-pound ultra-miniature television camera, makes possible direct observation of sites and events never before accessible by TV**

It fits lightly into the hand; it can be carried in a pocket; it weighs about a pound; it will go places too small for ordinary cameras, too dangerous for man; it will observe without being conspicuous; it may be mounted on a tripod, fastened to wall or bulkhead, hand-held by a pistol grip. Size: 1⅞" x 2⅜" x 4¾".

By means of a transistorized circuit and the new RCA half-inch Vidicon, the "Telemite" actually surpasses standard Vidicon-type industrial TV cameras in sensitivity. It produces clear, contrasty pictures with a scene illumination of 10-foot candles or less.

The "Telemite" operates with up to 200 feet of cable between it and the control monitor, and this distance can be further extended by using a repeater amplifier. This is the first TV camera to employ photoelectric sensitivity control, which provides automatic adaptation to widely varying scene illumination.

RCA Tmk(s) ®

DEFENSE ELECTRONIC PRODUCTS

**RADIO CORPORATION of AMERICA**

CAMDEN, N.J.

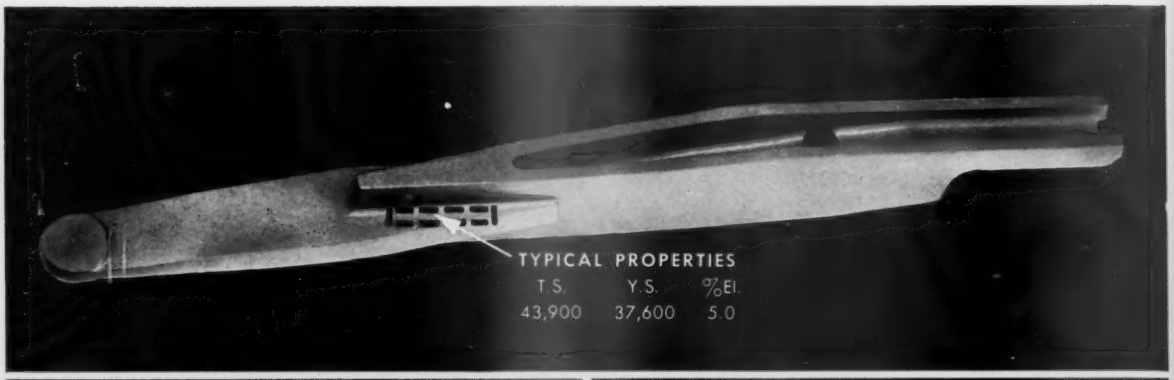
# NOW... *Ruggedized* PANEL METERS *with* LONG 250° SCALES

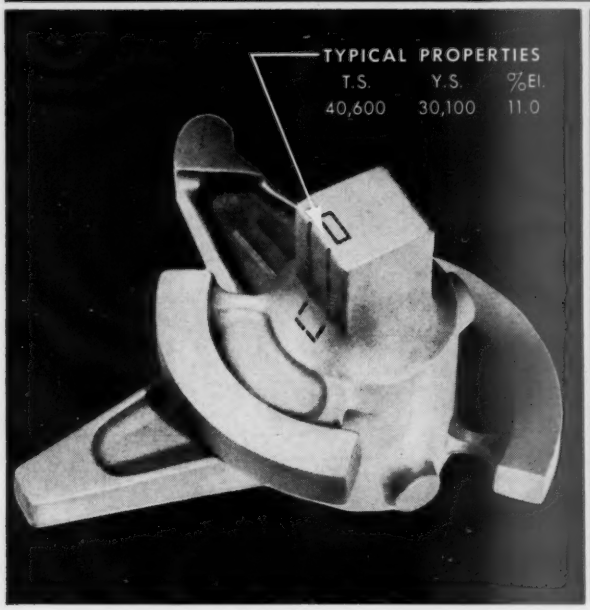
First with a comprehensive line of ruggedized d-c and a-c panel meters, Weston now provides these instruments in the popular 3½" size with *long readable scales, higher accuracy, improved sensitivities* and *superior ballistic characteristics.* Designed to meet, *and surpass in scale length and accuracy,* all requirements of MIL-M-10304A. They incorporate all Weston ruggedized design features including integrally molded and bonded shock mounting plates; shock-absorbing spring-backed jewels; screw driver type zero correctors, front sealed; anti-static treated plastic sealed windows; self shielding etc. For all the facts, consult your nearest Weston representative, or write—Weston Electrical Instrument Corporation, Newark 12, New Jersey.

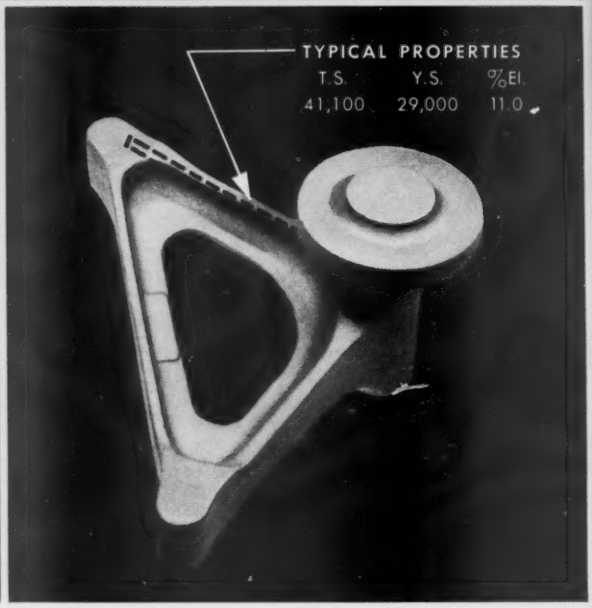
**WESTON** *Instruments*

A DAYSTROM UNIT

# HIGH-STRENGTH ALUMINUM CASTINGS




## YOU FLY THE CASTING, NOT THE TEST BAR

The designer gets guaranteed strength at the critical areas he selects in castings of Ductaluminum 356. And this strength is guaranteed *in the casting*, not the test bar. Result: Stronger castings without a weight penalty.

Production at Brake Shoe's new aluminum foundry in Mahwah, New Jersey, is devoted to aircraft and missile parts. Improved methods, developed in two years of pilot production, have given higher quality castings in both high-strength and commercial grades. Reliable casting soundness substantially eliminates the reject problem for customers who have switched to Brake Shoe. For more information on aluminum castings by Brake Shoe, write for our booklet "Ductaluminum 356."

### GUARANTEED PROPERTIES IN HIGHLY STRESSED AREAS

| | T.S., psi | Y.S., psi | %El. |
|---|---|---|---|
| Ductaluminum 356T | 38,000 | 28,000 | 6 |
| Ductaluminum 356S | 42,000 | 35,000 | 3 |

AMERICAN Brake Shoe COMPANY

LIGHT METALS DEPARTMENT
MAHWAH, NEW JERSEY

A-5810

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# IAS News Notes

October 1957

H. JULIAN ALLEN (F), Chief, High Speed Research Division, NACA Ames Laboratory, will discuss "Hypersonic Flight and the Re-Entry Problem" at the WRIGHT BROTHERS LECTURE, December 17. Mr. Allen was awarded NACA's Distinguished Service Medal this year for his contributions in this area and, in 1955, was awarded the Institute's Sylvanus Albert Reed Award. Among his most recent achievements is the discovery of blunting as a design feature to keep missile temperatures down.

THE IAS LIBRARY at National Headquarters receives 14 Russian scientific and technical periodicals of aeronautical interest from which selected articles are abstracted and published in the Aeronautical Reviews section of the Review. The original articles are available from the library on a loan basis.

A NEW AWARD, created in the will of the late Lawrence D. Bell to encourage helicopter research and experimentation, will be presented at the IAS Honors Night Dinner in January. Called the GROVER E. BELL AWARD, it will be presented by Leston Faneuf, President, Bell Aircraft Corporation. Further details next month.

* * * * * * *

## NATIONAL MEETINGS CALENDAR

| | |
|---|---|
| Oct. 21-22 | Canadian Aeronautical Institute - IAS Joint Meeting, Montreal, Canada. |
| Nov. 7-8 | Weapons System Management (National Midwestern Meeting), Statler-Hilton Hotel, Dallas, Texas. |
| Dec. 17 | Wright Brothers Lecture, Natural History Building Auditorium, Smithsonian Institution, Washington, D. C. "Hypersonic Flight and the Re-Entry Problem," by H. Julian Allen. |
| 1958 | |
| Jan. 27-31 | Twenty-Sixth Annual Meeting, Sheraton-Astor Hotel, New York. |
| Mar. 13-14 | Flight Propulsion Meeting (Classified), Hotel Carter, Cleveland. |
| May 12-14 | National Midwestern Meeting on Guided Missiles, Hotel Chase, St. Louis, Missouri. |
| Sept. 8-13 | First International Congress, International Council of the Aeronautical Sciences, Palace Hotel, Madrid, Spain. |

* * * * * * *

## JOINT MEETINGS CALENDAR

Mar. 17-21 1958 Nuclear Congress, International Amphitheatre, Chicago. Coordinated by Engineers Joint Council.

June 2-4 National Telemetering Conference, Lord Baltimore Hotel, Baltimore, Maryland. Sponsored by IAS, ARS, ISA, and AIEE.

June 19-21 1958 Heat Transfer and Fluid Mechanics Institute, University of California, Berkeley. Cosponsored by IAS.

## SECTION MEETINGS CALENDAR

Oct. 2 Philadelphia Section: Dinner Meeting, Penn - Sherwood Hotel. (Social period at 6:30, dinner at 7.) "Man in Space" by Captain Charles F. Gell, USN (MC).

Oct. 2 Wichita Section: Dinner Meeting, Innes-Colonial Room, 121 S. Broadway. (Social period at 6:30, dinner at 7.) "VTOL-STOL Aircraft" by Lee C. Lendphair.

Oct. 8 Los Angeles Section: Specialist Meeting, IAS Building, 8 p.m. "Hecker Method of Interior Temperature Calculations" by A. W. Trimpi.

Oct. 9 Texas Section: Specialist Meeting, Arlington State College Engineering Auditorium, 8 p.m. "Hydraulic Control System Testing Techniques" by Gilbert Voyles and Francis E. DePauw.

Oct. 15 Kansas City Section: Specialist Meeting, American Legion Memorial Building, Linwood Blvd. and Paseo, 8 p.m. "Development of the CJ-805" by Ray T. Lewis.

Oct. 16 Washington Section: Army aviation flight demonstration, Davidson Army Air Field, Fort Belvoir, Va., 4 p.m. (Dinner afterward.) Honorary Chairman - D. T. Barnard, Deputy Assistant Secretary of Defense for Research and Engineering. 3 speakers.

Oct. 17 Los Angeles Section: Dinner Meeting, IAS Building, 6:30 p.m. "Snark Program" by W. F. Ballhaus. (Classified Secret.)

Oct. 18 New York Section: Dinner Meeting, Sheraton McAlpin Hotel ballroom (Social hour at 6, dinner at 7, meeting at 8.) "Some Aspects of the National Guided Missile Program" by Vice-Adm. John H. Sides.

* * * * *

THE OPPORTUNITY ENCOMPASSED by the Institute's Flight Test Engineering Fellowship is presented in complete form on Page 31. Although the deadline for applications is March 1, 1958, early inquiries are invited.

REMINDER: The Review welcomes letters from Institute graded members who have changed affiliations or received recognition and endeavors to chronicle all such happenings. These announcements may be sent to News Editor, Review, at IAS National Headquarters.

N

## New high-temperature laminating resin

# EPON® 1310

*. . . retains strength to 500° F. and beyond!*

The "problem child" of supersonic speed is HEAT—causing laminating resins to lose strength and stability rapidly when pounded with excessive temperatures—

New Epon 1310 (formerly called Resin X-131) is the *first* epoxy resin to withstand 500° F. temperatures successfully.

When used in glass cloth laminates, Epon 1310 exhibits the long-term high-heat characteristics necessary for satisfactory performance of missiles and supersonic aircraft.

Epon 1310 is a *new* kind of epoxy resin, based on new chemistry. *It is unparalleled for all types of high-temperature applications.*

Perhaps Shell Epon 1310 or other Epon resins may be able to solve a design problem for you. For information, write us now.

***Epon resins** are the epoxy polymers made exclusively by Shell Chemical Corporation.*

**SHELL CHEMICAL CORPORATION**

**CHEMICAL SALES DIVISION 380 Madison Avenue, New York 17, New York**

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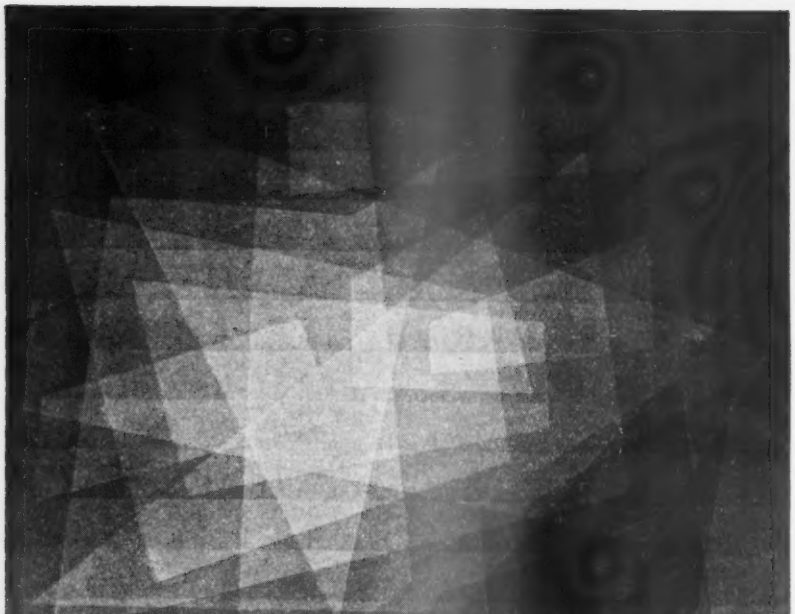
SHELL



"NIMBUS," a new painting by the well-known team of science-artists Simpson-Middleman, In this work, the creators have found new artistic meaning in the Moon and its reflected light. An attempt to capture the polarized nature of moonlight is made. The result, an almost half-light. Collection of the Whitney Museum of American Art, New York.

## Work in the world of supersonic flight—at Boeing

Supersonic flight is still in its infancy, and Boeing engineers are engaged in the adventurous task of pushing forward the frontiers of knowledge in this years-ahead world. Underway at Boeing are design projects for top-secret aircraft and missiles far more advanced than any yet developed. Related explorations delve into the required properties and capabilities of materials, fuels and systems not yet in existence. You'd find working on advanced Boeing projects a true adventure—challenging, rewarding, stature-building. Boeing offers this opportunity today to scientists, and to experienced engineers in many categories.

**BOEING**

*Drop a note now, to John C. Sanders, Engineering Personnel Administrator, Boeing Airplane Company, Department A-68, Seattle 24, Washington.*

IAS News

*A Record of People and Events of Interest to Institute Members*

# Weapons System Management Meeting Named First National Midwestern Meeting

*Program Lists 15 Technical Papers; ARDC Commander to Speak*

THE FIRST of a new series of IAS National Midwestern Meetings will be launched November 7 and 8 with the Weapons System Management Meeting at the Statler Hilton Hotel, Dallas, Tex.

The new meetings will be held annually in cities in the midcontinental region of the country. They will be national in scope and, in the established IAS tradition, will cover the entire field of aeronautical sciences, possibly taking specific branches as the subject for each meeting.

Plans are being made for the second National Midwestern Meeting in St. Louis, Mo., for 1958.

### Weapons System Management Program

A complete program for the Weapons System Management Meeting has been set up by members of the Texas Section. The meeting will present 15 technical sessions and a panel discussion.

Lieutenant Gen. Samuel E. Anderson, ARDC Commander, will be Guest Speaker at a banquet Thursday evening, November 7. Mundy I. Peale, President, IAS and Republic Aviation Corporation, will act as Toastmaster.

Papers, session chairmen, and sessions scheduled are:

**Thursday,** *Morning Session:* Chairman—Lt. Gen. Laurence C. Craigie, USAF (Ret.). "Concept of Weapons System Management," Gen. Orval R. Cook, USAF (Ret.), AIA President; "Purchasing for the B-58 Weapons System," Robert Kahn, Manager of Material, General Dynamics Corporation, Convair Division (Fort Worth); "Role of Operations Research," Howard F. Marx, Chief, Engineering Research, Temco Aircraft Corporation; and "Subsystem Design Evaluation," J. E. Goode, Chief, Aerophysics, Convair.

*Afternoon Session* (classified): Chairman—R. C. Blaylock, Vice-President, Engineering, Chance Vought Aircraft, Inc. "Weapons System Development of the Chance Vought F8U-1 'Crusader' Airplane," John R. Clark, Chief Engineer, Piloted Aircraft, Chance Vought; "Weapons System Management—The Impact on Aerodynamics," E. B. Maske, Chief, Aerodynamics, Convair; "Precision Navigation—Its Effect on Weapons Systems," S. F. Eyestone, Chief, Guidance Engineering Section, Autonetics Division, North American Aviation, Inc.; and "Structural Integration of the Weapon System," E. P. MacDonough, Project Engineer, F8U-3, Chance Vought.

**Friday,** *Morning Session* (classified): Chairman—I. N. Palley, Vice-President, Engineering, Temco. "Missile Propulsion," W. B. Briggs, Supervisor, Theoretical Propulsion, Chance Vought; "The Impact of Aerothermodynamic Factors on Modern Weapon System Management," W. A. Dorrance, Assistant to Director, Scientific Research, Convair; "Flight Testing," Dale Meyers, Chief Engineer, North American Missile Development Division; and "Management of an Army Guided Missile Program," Martin Schilling, Chief, Projects Management Staff, R&D Division, Redstone Arsenal.

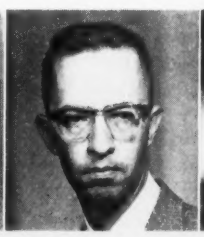
*Afternoon Session:* Chairman—A. C. Esenwein, Vice-President, Convair. "Reduced Cooling Requirements Through Integrated Design," Paul Petty, Senior Propulsion Engineer, Chance Vought; "Electronic Systems and Reliability," Frank W. Lehan, Associate Director, Electronics, The Ramo-Wooldridge Corporation; "Application of Weapons System Management Principles to New Problems," W. F. Ballhaus, Vice-President, Engineering, Northrop Aircraft, Inc.; and a management panel consisting of session chairmen who will answer questions submitted before the session begins. J. T. Cosby, B-58 Program Director, Convair, is Moderator.

R. J. Patton, Chairman of the Texas Section, is Chairman of the Meeting Arrangements Committee. C. L. Seacord is Meeting Program Chairman.

There will be informal luncheons, without speakers, on both days. Banquet and luncheon cancellation deadline is November 5; banquet dress is informal. Security clearance forms may be obtained from IAS Headquarters and returned to H. T. Johnson, 1004 University Drive, Fort Worth 7, Tex.

R. J. Patton

C. L. Seacord

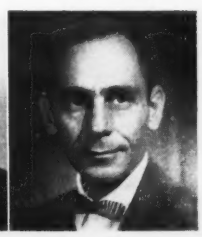


R. C. Blaylock

Lt. Gen. L. C. Craigie

A. C. Esenwein

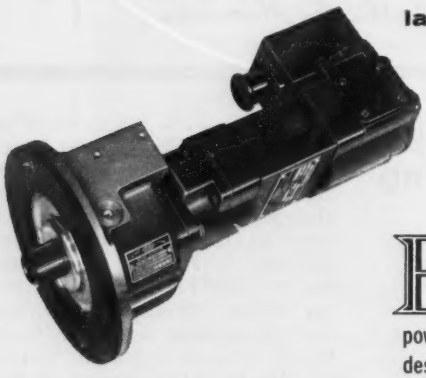
I. N. Palley



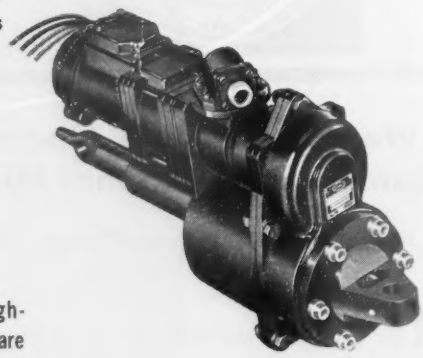
**Meeting the stringent requirements**
**of today's Missiles and Jet Aircraft**

# EEMCO ACTUATORS

**are now in use in the majority of our latest aerial weapons**

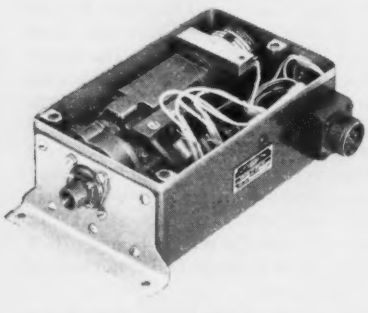


**Type:** D-925 Rotary Actuator for Missile Fin. **Output:** 400 inch-pounds @ 64 RPM, 24 volts, 27 amps. **Duty Cycle:** 1 minute on, 10 minutes off; **Gear Reduction:** 135 to 1 in 2.25" length; **Weight:** 6.75 lbs. **Meets Mil. Specs.:** MIL-A-8064 for actuators, MIL-M-8609 for motors.

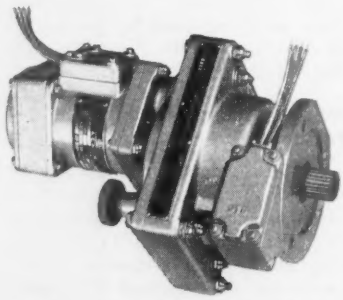


**Type:** D-818 Leading Edge Flap Actuator; **Weight:** 20.5 lbs. **Normal Operating Load:** 6,000 lbs.; **Maximum Operating Load:** 12,000 lbs. **Ultimate Static Load:** 24,000 lbs.; **Stroke:** 3.15"; **Rate of Travel:** .33" per second; **Amperes:** 3 amps at 480 cycles on 200 volts at the 6,000 lbs. load. **Meets Mil. Specs.:** MIL-A-8064 for actuators, MIL-M-7969A for motors.

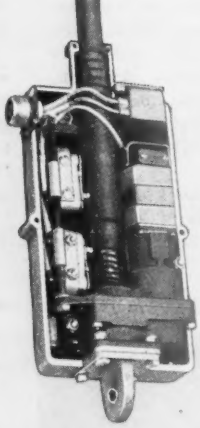
EEMCO's low-weight, high-power linear and rotary actuators are designed and engineered to give consistent, top-efficiency performance under the most extreme environmental conditions. The widespread use of these rugged components can only mean that the entire aircraft industry recognizes their built-in accuracy and reliability. EEMCO, in turn, recognizes the importance of adhering to strict production schedules, and will continue to assure prompt delivery.



**Type:** D-892 Power Package; **Size:** 7¼" x 4⅞" x 2¾". **Output:** 28 volts D.C., 1390 RPM at take-off shaft, 18 inch-oz. torque. **Weight:** 3⅜ lbs.; Operative in ambient temperatures to 250° F. **Meets Military Specifications:** MIL-A-8064 for actuators, MIL-M-8609 for motors.



**Type:** D-868 Rotary Actuator; **Weight:** 9⅞ lbs. **Power:** 200 volt, 400 cycle, 3-phase motor. **Ambient Temperature Range:** −65°F. to +400°F.; **Shaft Torque Limit:** Adjustable. **Load:** 1,650 inch-lbs. maximum to approx. 2 RPM on 1.5 amps. **Meets Military Specifications:** MIL-E-7894 and MIL-A-8064.



**Type:** D-607 Transport Door Actuator; **Weight:** 4.5 lbs. **Stroke:** 6.25"; **Operating Load:** 450 lbs.; **Ultimate Static Load:** 7150 lbs. tension; **Speed of Stroke:** under 450 lb. load—0.3" per second. **Size of Power Section:** 2¼" x 4½" x 8⅝". **Meets Mil. Specs.:** MIL-A-8064 for actuators, MIL-M-8609 for motors.

**Type:** D-822 Trailing Edge Flap Rotary Actuator; **Weight:** 35 lbs. **Normal Operating Load:** 26,000 inch-lbs. **Maximum Operating Load:** 52,000 inch-lbs. **Ultimate Static Load:** 75,000 inch-lbs.; **Travel:** 45 degrees at .625 RPM; **Amperes:** 4 amps at 26,000 inch-lbs. at 480 cycles on 200 volts. **Frequency Range:** 380 to 420 cycles. **Meets Mil. Specs.:** MIL-A-8064 for actuators, MIL-M-7969A.

**EEMCO ELECTRICAL ENGINEERING & MANUFACTURING CORP.**

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3-551

## Experimental Aerodynamics Center Begins Second Class

The Training Center for Experimental Aerodynamics has announced that its second class in experimental aerodynamics is scheduled to begin this month, at Rhode-Saint-Genese, Belgium.

The first class of 16 students from ten NATO countries was graduated July 13. The Center was established in October, 1956, at the suggestion of Theodore von Kármán, AGARD Chairman, and was set up as a joint effort of Belgium and the United States.

The Center provides an opportunity for engineers and scientists from NATO countries to obtain an intensive training in experimental aerodynamics and in the broad field of fluid mechanics. About 75 per cent of the course is devoted to experimental work to enable students to develop the techniques and practices used in a modern aerodynamics laboratory.

R. Paul Harrington (AF) is Technical Director of TCEA. A staff of five professors and five technical engineers is augmented from time to time by scientists of various nations who give lectures and demonstrations. In addition, several visits are scheduled to outstanding aerodynamic facilities in neighboring countries. No tuition fee is charged.

Engineers and scientists may obtain further information by writing to Dr. R. P. Harrington, Technical Director, Training Center for Experimental Aerodynamics, 72, Chaussee de Waterloo, Rhode-Saint-Genese, Belgium.

**Allan Chilton (F) has been appointed Manager, Engineering Center for Corporate Advanced Design and Development Programs, Westinghouse Electric Corp. His previous assignment was Chief Engineer of the Westinghouse Aviation Gas Turbine Division, Kansas City, Mo.**

## NEWS OF MEMBERS

▸ **Nicholas J. Hoff** (F) has left his post as Professor and Head, Aeronautical Engineering Department, Polytechnic Institute of Brooklyn, to assume duties as Executive Head, Division of Aeronautical Engineering, Stanford University.

▸ **Shih-I Pai** (AF), Associate Professor, Institute of Fluid Dynamics and Applied Mathematics, University of Maryland, is on a sabbatical leave in Germany until July, 1958. Recipient of a Guggenheim Fellowship, Dr. Pai will attend the Institut fuer Theoretische Gas Dynamik, Deutsche Versuchsanstalt fuer Luftfahrt, Aachen.

**Members on the move . . . .**

*This section provides information concerning the latest affiliations of IAS members. All members are urged to notify the News Editor of changes as soon as they occur.*

**Jack M. Abercrombie** (A), formerly an Associate Engineer, Douglas Aircraft Company (Tulsa), has been placed on active duty with the Air Force as Project Officer, Tow Target Testing Branch, Air Force Armament Center, Eglin AFB, Fla.

**Alfred A. Adler** (M), formerly associated with the Aerodynamic Research Department, Cornell Aeronautical Laboratory, Inc., has joined the Research Division, Bell Aircraft Corporation.

**Col. Albert A. Arnhym** (AF), formerly Director of Information Services, ARDC, has been assigned as Special Assistant to the Commander in Chief, Strategic Air Command, at Offutt AFB, Neb.

**Harry M. Baldwin** (A), formerly General Foreman, Quality Control Services, Lycoming Division, Avco Manufacturing Corporation, has joined the Florida Operation, Pratt & Whitney Aircraft Division, United Aircraft Corporation, as General Foreman, Engineering Inspection.

**Claude W. Brenner** (M) has been appointed Chief Project Engineer, Aeronautical and Mechanical Division, Allied Research Associates, Inc. He had been a Project Engineer for the firm.

**E. L. Eveleth** (M), formerly Assistant Sales Manager, Customer Services, United Aircraft Corporation's Sikorsky Aircraft Division, has resigned to become Vice-President and General Manager, Southeast Machinery Company, Fort Lauderdale, Fla.

**Daniel J. Fink** (M) has been appointed Chief Engineer, Aeronautical and Mechanical Division, Allied Research Associates, Inc. He had been Chief Project Engineer.

**William W. Fox** (A), Senior Project Engineer for Convair's F-102A for the past 3 years, has been appointed Special Assistant F-102/F-106.

**Donald P. Germeraad** (AF), Vice-Chairman of the Institute's San Diego Section and Chief Engineering Test Pilot for Convair, A Division of General Dynamics Corporation, has been appointed Chief Pilot on the Convair 880 flight-test program.

**George Z. Habermass** (A), Type (Qualification) Test Engineer, High and Low Pressure Aircraft Pneumatic Equipment, The Hymatic Engineering Co.

## Competition Open, Forms Available Now for IAS Flight-Test Engineering Fellowship

Do you have a Bachelor's degree in engineering?

Will you have one before June, 1958?

Your degree and United States citizenship are all you need to qualify as a candidate for the Institute of the Aeronautical Sciences Flight-Test Engineering Fellowship. The Institute invites you to enter the 1958 competition.

The winner or winners will join Air Force and Navy test pilots in a specially designed program providing a solid foundation of advanced technical training in the science of test flight.

Application forms may be obtained by a request in writing (endorsed by a sponsor) addressed to Flight Test, Institute of the Aeronautical Sciences, 2 East 64th Street, New York 21, N.Y.

Closing date for applications is March 1, 1958.

The Fellowship award has a total value of $4,700. A First-Year Fellow receives $1,500 as stipend and $600 for tuition. A Second-Year Fellow receives a $2,000 stipend and another $600 for tuition. Second-year renewal depends upon satisfactory performance during the first year.

Two years of graduate study are pursued at Princeton University, where Flight-Test Engineering has been taught to military pilots for several years. Princeton departmental expenses are covered by the Fellowship.

The program offered is adjustable. Candidates may be enrolled in an educational institution or employed in industry when making application.

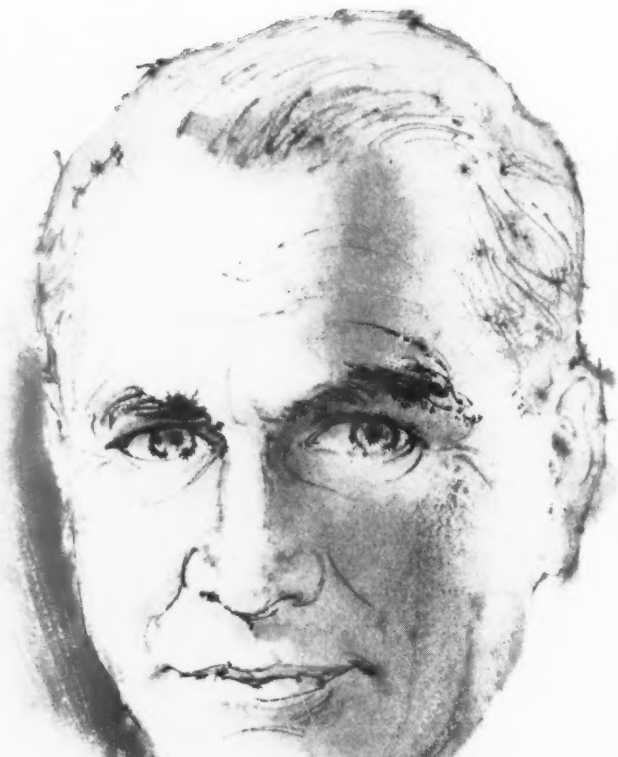
# EXPERIENCE
## is the best feature

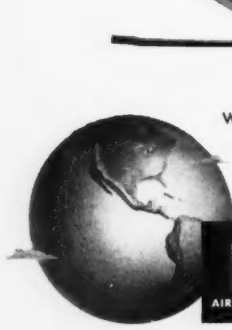
Management men say experience put Rohr on top in major aircraft components. For, at Rohr, there's more than vast experience in design, engineering and production . . . there's the vital know-how to conceive and construct ingenious machines that build better products at lower cost.

Long experience has led to Rohr's *world leadership in the design and production of ready-to-install power packages for airplanes.*

Furthermore, today Rohr leads in design and development in advanced aircraft structures programs such as years-ahead high strength weldments (shown below).

In aircraft components, experience is the best feature. It's a vital part of the 30,000 different parts built by Rohr.





World's largest producer of ready-to-install power packages for airplanes.

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AIRCRAFT CORPORATION

Main Plant and Headquarters: Chula Vista, Calif.
Plant: Riverside, Calif.
Assembly Plants: Winder, Georgia; Auburn, Washington

Career opportunities for engineers and technicians.

Ltd., has been elected an Associate of the Royal Aeronautical Society.

**Thomas Jesse Harris** (A), formerly Director, Freight Sales, American Airlines, Inc., has joined Aero Design & Engineering Company as Director of Marketing.

**George A. Hoffman** (M), a Structural Engineer with The RAND Corporation, has been appointed to a panel of the National Academy of Sciences, to help recommend research for the structural use of beryllium. An article on beryllium as an aircraft structural material by Dr. Hoffman appeared in the February, 1957, REVIEW.

**James B. Kendrick** (AF) recently completed an assignment as Chief, Preliminary Design and Special Projects, Aerophysics Development Corporation, and has joined the Technical Staff, Guided Missile Research Division, The Ramo-Wooldridge Corporation.

**Bernard M. Leadon** (M), formerly Lecturer in Aeronautical Engineering, University of Minnesota, has joined Convair, A Division of General Dynamics Corporation (San Diego), as Chief Staff Scientist under C. L. Critchfield.

**Bernard P. Miller** (M), formerly Captain, USAF, and Head, Thermodynamics Group, Department of Marine Engineering, USNA, has joined the Special Systems and Development Department of the Radio Corporation of America as a Member of the Technical Staff.

**Louis D. Nelson** (M), who had been Preliminary Design Engineer for Beech Aircraft Corporation, has joined Temco Aircraft Corporation as Group Engineer, Propulsion.

**Gladyn H. Putt** (AF), formerly a Research Administrator with The RAND Corporation, has been appointed the executive asssitant to L. Eugene Root, Vice-President of Lockheed Aircraft Corporation and General Manager of its Missile Systems Division.

**Josiah E. Smith** (M), formerly Associate Director, Southern California Cooperative Wind Tunnel, has joined the Guided Missile Research Division, The Ramo-Wooldridge Corporation.

**George Sonnemann** (M), formerly Senior Engineer directing the Bettis Plant Fellowship and Reactor Engineering programs, Westinghouse Electric Corporation, has accepted the chair of Westinghouse Professor of Mechanical Engineering at the University of Pittsburgh.

**W. Thomas Stark** (M) has been appointed to the new post of General Sales Manager, Aviation Products at Fairchild Engine and Airplane Corporation's Stratos Division. He formerly was Manager of Special Products and Military Sales, American Bosch Division, American Bosch Arma Corporation.

**Bernard H. Wallach** (M), former Staff Engineer, Kearfott Company, Inc., subsidiary of General Precision Equipment Corporation, is now Chief Research Mechanical Engineer with David Bogen Co., Inc.-Presto Recording Corp. of Paramus, N.J.

**Lt. Col. Edmund G. Wodrich, USAF** (AF), formerly Executive, Office of the Assistant for Standardization, DCS/Development, Hq USAF, Washington, D.C., has been named Chief, Range Control Division, Directorate of Range Operations, Hq Air Force Missile Test Center, Patrick AFB, Fla.

## Necrology

### Claude M. Fligg

News of the death on May 6 of Capt. Claude M. Fligg, USN (Ret.) (AF), has reached the Institute. He was 52.

At the time of his death, Captain Fligg was a Structures Engineer for Lockheed Aircraft Corporation.

Born September 27, 1904, at Hood River, Ore., he was a 1930 graduate of the University of Washington College of Engineering. From 1931 to 1935, he worked for the Boeing Airplane Company as a Layout Draftsman and Stress Engineer. He was a Junior Aeronautical Engineer at Langley Field (NACA) from 1935 to 1938, when he became an Associate Aeronautical Engineer for the CAA.

During World War II, Captain Fligg received the Legion of Merit and the Bronze Star three times. He served as Executive Officer on the U.S.S. "St. Paul" during the Korean conflict and in his last command was Commodore of Squadron Nine, Mine Forces Pacific.

### Gilbert P. Haven

The Institute has received word of the death of Gilbert P. Haven (M), Experimental Test Pilot, Pratt & Whitney Aircraft Division, United Aircraft Corporation. He was 37.

Born June 5, 1920, in Youngstown, Ohio, Mr. Haven was an engineering graduate of Lehigh University and a professional pilot.

He was a Flight Instructor for Lehigh Aircraft Company from 1941 to 1943 and at the same time an Instructor in Aeronautics at Muhlenberg College.

He became a test pilot for Pratt & Whitney in 1943.

### Willis I. Milham

Word of the death of Prof. Willis I. Milham (AF), who taught at Williams College since 1902, has reached the Institute. Professor Milham, 83, died on March 23.

Professor Milham began teaching meteorology at Williams in 1903 and in addition taught physics, mathematics, astronomy, and air navigation.

Born in Kinderhook, N.Y., in 1874, he received his B.A. from Williams in 1894, his M.A. in 1895, and a Ph.D. from the University of Strasbourg in 1900.

Besides the Institute, Professor Milham also had been a member of the American Association for the Advancement of Science, the American Physical Association, Société Belge d'Astronomie, and Société d'Astronomie de France.

## CORPORATE MEMBER NEWS

• **Aeronutronic Systems, Inc.,** has announced it will launch the rocket vehicle in the Air Force's "Operation Far Side." The firm is the prime contractor for the project with responsibility for the design fabrication and firing of the high-altitude rocket. The rocket will be carried by a balloon to 100,000 ft. before being launched.

• **Aircraft Radio Corporation** has announced that a fourth unit has been added to its assortment of packaged relays. Known as the ARC Type K-18 relay, the newest unit is said to be a single-pole, double-throw, coaxial relay assembly in a protective housing for switching VHF and UHF at low voltage and low current.

• **Allied Research Associates, Inc.,** has recently been reorganized into four divisions: Aeronautical and Mechanical Engineering Division, Electronics and Systems Engineering Division, Physical Sciences Division, and the Development and Production Facility Division.

• **Aluminum Company of America** has developed a new alloy for welded aluminum structures which must operate at moderately elevated temperatures. The firm reports this alloy, X5454, provides maximum strength for aluminum applications exposed continuously or intermittently to 150°–300°F. temperature ranges, displays high resistance to corrosion and stress corrosion, and may be cold formed. . . . Aluminum powder metallurgy products (APMP), created by subjecting the powdered metal to heat and pressure, now are available from Alcoa in the form of extruded shapes, forgings, sheet, foil, drawn and extruded tube, impact extrusions, fasteners, and wires. These products are said to be stronger and more stable above 400°F. than aluminum alloys produced by the conventional method. . . . The company has made available a selected bibliography from its library for designers and design engineers in the metalworking industry. . . . A $54 million expansion for the firm's Davenport, Ia., plant has been announced.

• **American Airlines, Inc.,** has announced daily DC-7 Mercury nonstop service between St. Louis, Mo., and New York, N.Y.

(*Continued on page 86*)

**A** Two extension coil springs hold assembly against shaft.

**B** Axial compression springs exert constant positive pressure toward the sealing face.

**C** Key and pin assemblies lock carbon segments against rotation.

# KOPPERS CIRCUMFERENTIAL SEAL

## PROVIDES UP TO 2000 hrs. OF PERFORMANCE

**CAN USE LESS THAN 5 h.p.**

**D** Flexible sealing segments permit seal to achieve same circularity as shaft.

**E** Straight-cut joints are covered and sealed by segmental cover ring and segmental back ring.

A number of finite joint gaps allow for ring wear.

Koppers Circumferential Seal is a segmented carbon seal ring with straight-cut joints. Its design can be modified to use step type joints or step seal joints. Primarily a gas seal, the Koppers Circumferential Seal will seal liquids if the geometry of the shaft mating faces is changed.

Koppers Circumferential Seals are one of a large variety of seals designed and manufactured by Koppers for every industrial use. Because of this complete line, Koppers can recommend, without bias, the seal best suited to your specific application. And Koppers continuous development and testing of new designs and new materials assure you of the most advanced, most efficient seals for your purpose. If you have a sealing problem, write to the KOPPERS COMPANY, INC., Metal Products Division, Piston Ring and Seal Department, 2210 Scott St., Baltimore 3, Maryland.

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KOPPERS

**MECHANICAL SHAFT SEALS**

# DATELINE World

PROFESSIONAL NOTES AND REPORTS

*Engineering and Scientific Briefs from Correspondents Around the Globe*

### Plastic Properties of Metals Revealed by New Soviet Method

◆ A new Soviet method of determining the hot plasticity properties of steel has been revealed. The technique is based on the ability of a strip of metal to bend under an imposed load and is taken up in a paper by I. A. Formichev entitled "New Method of Testing the Plastic Properties of Metals at High Temperatures."

According to the author, a strip of metal supported at the ends is given a load applied by a punch. Movement of the punch before the test section breaks, which corresponds to the depth to which the strip is bent, is a measure of plasticity and, therefore, hot workability. The moment of failure is judged by autographic load diagrams.

When carried out at various temperatures, the test gives an indication as to the best hot-working temperature range and is held particularly suitable in predicting optimum temperatures for rotary piercing since stress conditions are similar.

Use of this method has appreciably facilitated establishment of best working conditions for piercing seamless tubes of new grades of steel with limited plasticity.

### Transformation of Steel Subject of Two Soviet Papers

◆ Recent Soviet papers by A. P. Gulyayev and V. M. Zalkin, report research on the transformation of steel. In the first paper, "On the Kinetics of Isothermal Formation of Austenite," the Soviet authors point out that previous investigators have reached false conclusions because they generally heated specimens in salt or liquid metal baths and ignored the transformation during heating to the isothermal holding temperature. Also they based their data for "incubation time" on the elapsed time after reaching the holding temperature.

The present work was based on electric heating at a rate of 60°/sec.; isothermal holding temperatures were 745°, 755°, and 770°C. Very short holding times could thus be studied directly and not by extrapolation. The steel was U-8 with a lamellar pearlitic structure; the amount of transformation was determined microscopically after water quenching. The authors report that

(1) No incubation period was observed.

(2) The start of isothermal transformation did not coincide with the start of transformation. In other words, the "isothermal" formation of austenite consisted of two parts—processes taking place on heating from $A_1$ to the holding temperature and processes actually occurring during holding at constant temperature.

(3) Therefore a schematic diagram could be constructed to show the effect of heating rate on the isothermal formation of austenite. With increasing heating rate to the holding temperature, the time necessary for complete transformation at this temperature increases since less transformation occurs during heating to the holding temperature.

The second paper, "On the Theory of Phase Transformations in Steel on Heating," reports a study similar to the first, covering transformation on continuous heating. Most of the tests were made with heating rates of 10 to 350°C./sec.; one was carried out with a rate of 850°C./sec. According to the authors:

(1) With continuous heating, the intermediate stages of transformation took place at a constant temperature. With a heating rate of 160°C./sec., the transformation was isothermal from 35–40 per cent to 60–65 per cent of the new phase. With higher heating rates, the initial and final stages of transformation accounted for more of the transformation; while the intermediate (isothermal) period was shortened and shifted to higher temperatures. With sufficiently high heating rate (850°C./sec.), no isothermal period was observed.

(2) The curves for kinetic transformation with continuous cooling were not symmetric, as was the case with isothermal transformation.

(3) The higher the heating rate, the wider was the temperature range over which transformation took place.

### Isotope Separation System May Save Germans Millions

◆ A new process for separating atomic isotopes promises to save many millions of dollars for Western Germany, which has been unable to utilize the wasteful diffusion method in large-scale development of atomic power.

In addition to its economy, quicker results have been recorded by the new process. It was developed at the Institute for Physical Chemistry at Bonn University.

The method consists in part of introducing gas obtained from reduction of raw uranium ore into a long, narrow metal tube containing an extremely high speed rotating device. Separation of U-235 atoms from the heavier uranium atoms ensues.

Following thorough tests, the centrifugal apparatus soon will go into mass production.

## *Air Mail*

**Letters to the Review**

EDITOR:

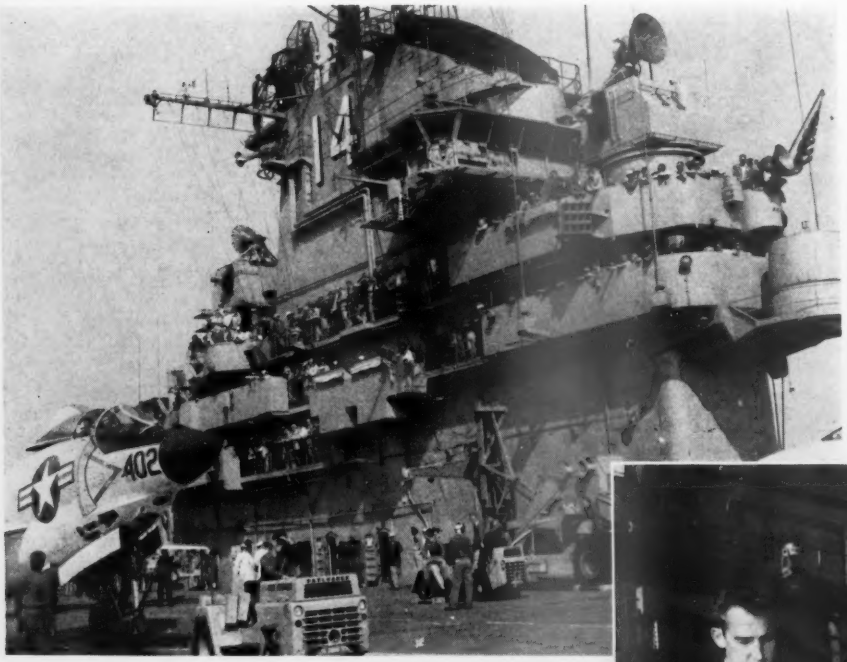
Thank you for printing the article on the delightful tabletop supersonic wind tunnel in your July issue (pp. 31, 33). Having built two wind tunnels in England at a cost of 100,000 times that of the little one, I am quite inspired to think that I can provide myself with a small wind tunnel out of my pocket money, and I am contemplating building a slightly larger tunnel for Mach Number 4, costing perhaps $50.

I would like to correct a small error in the article. It is stated that the limitation on Mach Number is due to the pressure obtainable by the hand pump, but in fact it can only be due to a slight error in the geometry of the supersonic nozzle. The geometry fixes the Mach Number, and the flow will stay at Mach 1.7 from the moment the air at 100 psig is released into the nozzle until the reservoir pressure falls to about 10 psig, a second later, when the flow will abruptly become subsonic. A store at 150 psig which will run a Mach 1.7 nozzle for 1 sec. will probably run a Mach 2.5 nozzle for 0.5 sec. and a Mach 3 nozzle for 0.2 sec. with the same size working section.

RONALD S. H. TOMS, MIAS
Research Associate, Engineering Center
University of Southern California

# Anchors Aweigh—

# *Navy Joins IAS in Sponsoring*



The 1,400 registrants for the National Naval Aviation Meeting in San Diego, August 5–10, were treated to one of the most enlightening and fruitful meetings ever sponsored by the Institute. Only those of us who were privileged to attend can appreciate the tremendous effort that was put forth by the Navy and the committee members of the IAS San Diego Section to bring this about. To each and every one of these individuals, both military and civilian, who had a part in the show, we gratefully say—"Well Done!"

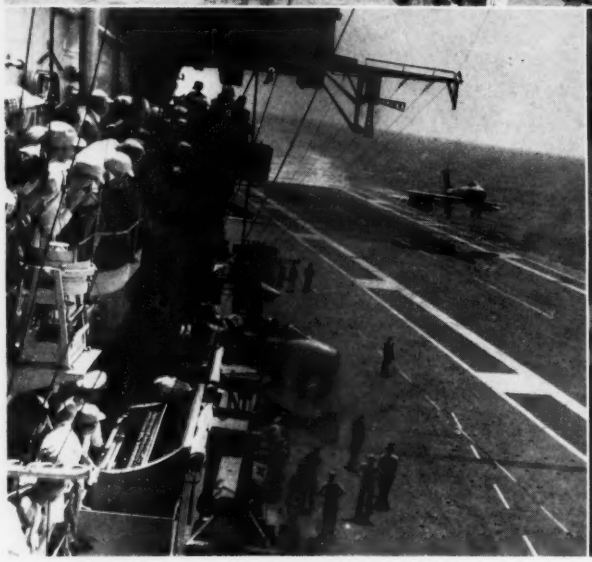
Time and space for this issue do not permit a detailed account of the week's varied program or personal acknowledgments to the dedicated people involved. It is hoped, therefore, that the following pictorial pages will partially convey the story and give some idea of the credits deserved.

Papers presented at the unclassified sessions are being published in a single volume of *Proceedings*. Included in this volume, also, are the full contexts of the luncheon and dinner speeches and a reproduction of these pictorial pages. These *Proceedings* are obtainable through the Institute's Special Publications Department in New York. (See page 53.)

W.A.S.

***(Top)*** **IAS delegates line island structure of the U.S.S. "Ticonderoga" as operations get under way on the classified carrier trip, August 7.** ***(Bottom)*** **William H. Mollering, General Chairman of the meeting, presents model of the "Ticonderoga" to its Commanding Officer, Capt. William A. Stuart, USN.**

# *One of Year's Outstanding Meetings*

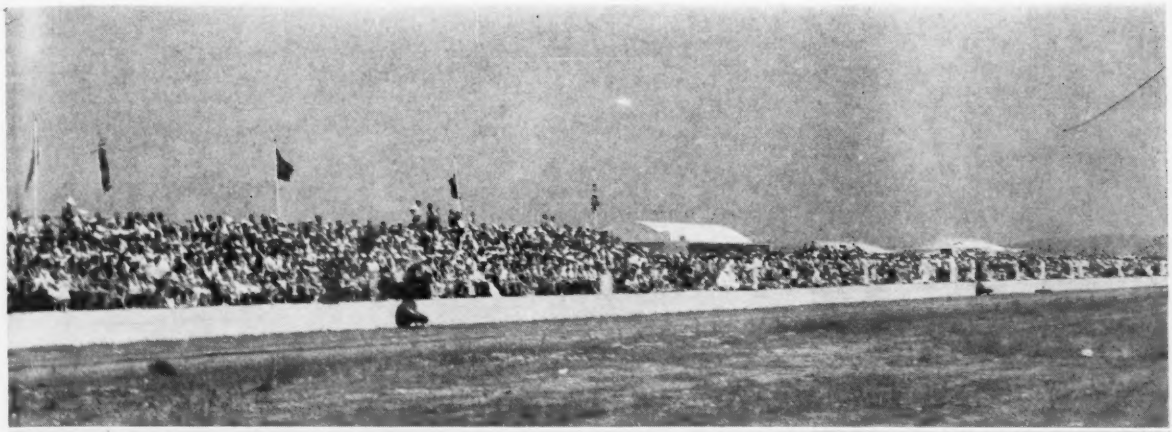


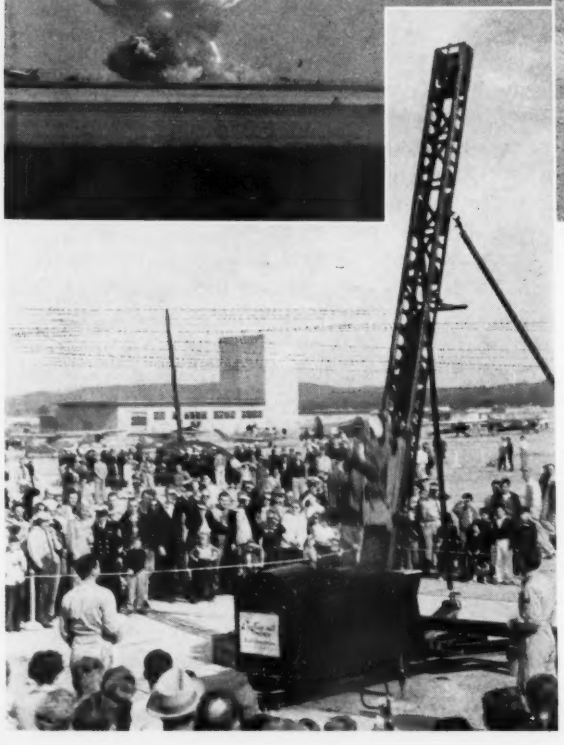
**The launching of a "Regulus" missile from the U.S.S. "Los Angeles" *(top)* and the landings and operations aboard the "Ticonderoga" *(left)* proved extremely interesting to IAS members. Of no less interest, and greeted with the same enthusiasm, was the Navy chow served all guests in Hangar Bay #1 *(right)*.**

## Naval Meeting *(Continued)*

The history of Naval aviation from 1911 to 1957 was portrayed at the Institute's San Diego Building during the entire week of the meeting. Over 100 models and many photographs and murals, on loan from the Smithsonian Institution and flown out by the Navy for the occasion, proved a great attraction.

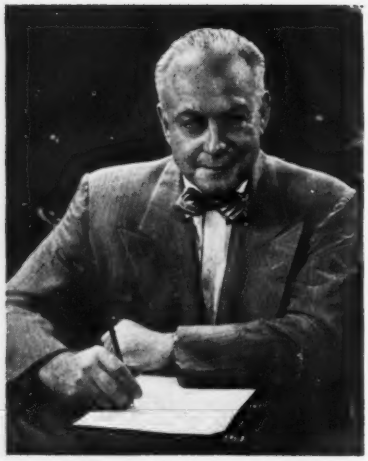
*(Right)* Peter A. Beck, Exhibit Chairman, prepares to cut ribbon opening the display to the public, flanked by *(left to right)* Rear Adm. Joseph Cline, USN (Ret.); Paul E. Garber, Curator and Acting Head, National Air Museum, Smithsonian Institution; Alfred Verville, Technical Advisor, Technical Data Division, USN BuAer; Rear Adm. E. Dodson, USN; (Beck); Reuben H. Fleet, IAS Past President and founder of Consolidated Aircraft Corporation; and Comdr. "Zeke" Cornier, USN. *(Below)* Navy's crackcdrill team parades in front of IAS building during opening ceremonies. *(Bottom)* A very partial view of the display in the auditorium room of the IAS building.





The week-long meeting was climaxed on Saturday by a spectacular show put on by the Navy and Marines at Miramar Naval Air Station. This included a static display of latest aircraft and equipment, demonstrations of many tactics and techniques, and a flying show that featured the Navy Blue Angels and a U.S. Marine Corps vertical envelopment demonstration.

*(Top)* A section of the grandstand reserved for IAS members and registrants of the National Naval Aviation Meeting. *(Center)* A vertical envelopment by the U.S. Marine Corps immediately following a simulated atom bomb attack by an A4D Skyhawk *(center, left)*. *(Bottom)* An ejection seat trainer being demonstrated to the visitors.



GUEST EDITORIAL

**by J. H. Kindelberger**
Chairman of the Board
North American Aviation, Inc.
Past President, IAS

# THE NAVY AND INDUSTRY—*Partners*

A LOT OF things have happened and a lot of things have changed since the "Old Navy," when a handful of devoted men with almost no money but with great enthusiasm tackled a new conception in an atmosphere of antagonism and resistance. But it is remarkable how many of the problems that plagued the pioneers are still with us in spite of our tremendous technical achievements.

Then, as now, the trouble was money and confusion—confusion with a capital "K." The total appropriations for naval aviation from 1912 to 1915 were $60,000. Tucked away in quarters of the Chief of Naval Operations, an Office of Aviation vainly attempted to coordinate activities of the Bureaus. Responsibility was divided along the lines laid down for ships—an arrangement bound to result in a continuous struggle for both money and power. Boards and committees met, considered and made recommendations, and, like as not, another board or committee was appointed. Usually, the end of carefully laid plans was lack of money.

At the start of 1917, the commissioned personnel in naval aviation numbered 59, of whom only 26 were aviators and 30 were students, the other three being our old Naval Constructor friends, "Captain Dick" Richardson, Westervelt, and Hunsaker.

Total Navy personnel assigned to aviation was measured at just over 400. The small nucleus upon which to build a wartime air force consisted of 57 air vehicles including two kite balloons.

These were the handicaps, yet at the time of the Armistice the Naval Air Service was composed of 3,117 officers and 45,632 enlisted men. Forty-two air stations were in commission, 25 in foreign lands.

Then, after the Armistice, naval aviation was limited by Congress to six seaplane stations within the continental limits of the United States, and a corresponding reduction of personnel and equipment ensued.

To add to the problems, a very familiar argument was being developed. This was none other than our still lively friend—Roles and Missions—and, with other problems, resulted in creation of a permanent group known as the Aeronautical Board. Composed of Army and Navy officers, it warred on merrily from 1919 until its elimination in 1948, when the Department of Defense was reorganized and the war was taken up by the Joint Chiefs of Staff.

It is not possible to think back on the days of the early twenties without a few words about that great friend of the Navy, Brig. Gen. William A. Mitchell. In his fight for a separate Air Force, the General had awakened the Navy to the fact that there was grave danger of losing Naval Air. Faced by this threat, the Navy closed ranks and in 1921 created the Bureau of Aeronautics under Rear Adm. William A. Moffett. Admiral Moffett served as Chief of the Bureau for 12 years, during which time his great ability as an administrator, diplomat, and public relations man was continuously demonstrated as he steered a course through obstacles that threatened many times to swamp the somewhat cranky boat he guided.

Our good friend, Jerry Hunsaker, had much to do with the organization of the new Bureau, just as he had guided the engineering and policy before its inauguration. His contributions were many and important.

In line with my comment about problems of the early days still being with us, I can observe that again we are struggling with a very stringent budget. In fact, the Navy will have somewhat less than $3,000 millions to spend on materiel. And there appears to be one important new grievance—renegotiation.

Many of you doubtless recall the 1924 House of Representatives "Inquiry into Operations of the U.S. Air Service." Early hearings of this group covered air industry grievances, chief among which were (1) the existing system of bidding for contracts; (2) the lack of continuity in governmental procurement programs; (3) the competition with private firms by the Naval

Luncheon Address, National Naval Aviation Meeting, San Diego, Calif., Aug. 5–10, 1957.

*Those concerned with American air progress learned first hand at the Naval Aviation Meeting that problems may harass progress but cannot defeat it. Examples are cited herein by one who modestly left his own name off the list of pioneers this country has to thank for its air supremacy. Mr. Kindelberger's complete talk will be published in the Naval Aviation Meeting Proceedings.*

# *for Air Progress*

Aircraft Factory; (4) the difficulty of financing; and, as a result of the others (5) low morale of the industry. This special investigating committee was headed by Representative Lampert of Wisconsin and over a period of months conducted hearings, including visits to military establishments and plants.

The *first* of these grievances was of great importance because the making of contracts had long been a difficult problem. This was due to the fact that the contracts were affected by laws, some going back to 1809, which provided for competitive bidding and bound the Government to accept the lowest bid without any demonstration that the low bidder could make good. Consequently, use was made of the negotiated contract because a certain firm was the only one capable of making the item, and there were also development contracts let, under which a qualified firm undertook at an estimated cost the making of a model embodying a Naval design.

Back in those days, and for some time to follow, the design of a particular type airplane was made in the Bureau of Aeronautics, and the drawings and specifications were then sent to the industry. With such a type contract, patents frequently were involved, resulting from improvements over the original design furnished by the Navy, and of course the question of proprietary rights was always present. There were instances in which firms that had gone to considerable effort under development contracts found themselves confronted with competitive bids for mass production, only to lose the production contract to a lower bidder.

The *second* of these grievances was the lack of continuity in Government procurement programs. This has been with us forever, and it happens to be on our doorstep again today. It is especially important now that, following the build-up since Korea, there happens to be a lot of excess capacity in the aircraft business and because the newer airplanes, missiles, and so on are so expensive that fewer can be procured.

The *third* of these grievances was the competition with private firms by the Naval Aircraft Factory. Fortunately, this is nonexistent today, but the industry is still complaining along the same line about the development and manufacture of many items by various Government institutions which industry thinks are naturally part of its work.

The *fourth* of these grievances was the difficulty of financing. To be sure, this has been very much alleviated in recent years, but I am quite certain that, with the cutbacks, cancellations, stretchouts, and renegotiation, financing from now on will be extremely difficult.

Now for some years we at North American have had the privilege of working with the Bureau of Aeronautics in many aspects of naval aviation progress. It has given us a tremendous satisfaction and occasionally even a little profit.

(That word profit, by the way, is a technical term that may be unfamiliar to many of the youngsters here. It refers to money that used to be left over after you did a good job and that you plowed back into the business so you could do a better job next time. Nowadays the term has fallen into disuse, and the measure of how good a job you have done is the amount of money the Renegotiation Board assesses you 5 years after you spent it. This gets a little complicated before long.)

It is impossible to look back to the beginnings of aviation without being impressed strongly by the character and achievements of the men who pioneered for the Navy, for the Army, and for aviation in general. Theirs was a little understood cause, confounded by ignorance and obstructed by lethargy and the orderly habits of the trained military mind. They were men of many talents who not only flew in the machines but helped design them, in many cases built them, and in all cases fought the uphill battle for the acceptance of aviation by those who had not seen the vision. They were men like Jack Towers, Putty Read, Jerry Hunsaker, and Pat Bellinger—to name only a few of the Navy. There also were men like Hap Arnold, Glenn Curtiss, Glenn Martin, and of course at the top of the list the Wright brothers. These great pioneering leaders carried aviation through the years of invention, experimentation, and improvement. In most instances they lived to carry their leadership into World War II and the final conclusive demonstration.

Of great significance also is the close relationship between the industry and Navy through the years that has made much of the progress possible. Of course, there have been and are problems, but these have never gotten in the way of the basic job of engineering and producing the equipment required for the Navy mission. We always have fought for a reasonable and sound basis for procurement and a fair application of competitive principles because we believe that the long-range interest of the Government and the industry depends on this approach. I fail to find an instance, however, when the business problems have obscured the main objective of developing and delivering the best possible equipment. And I think the record speaks for itself.

# For Naval Aviation

# *A Bright Future ...*

Excerpts from the

Dinner Address

by

**The Honorable**
**Thomas Gates, Jr.**

**Secretary of the Navy**

San Diego, Calif.

August 5, 1957

THIS IS A time of decision. Decisions have been taken in recent weeks—are being taken today—and will be taken in the next year which will affect our country for many years to come. These are difficult decisions. Some groups would resolve them with deceptively simple changes in the Defense organization. This is no answer. There are no easy, obvious answers. They must evolve with knowledge. The decisions will have profound effect on us all—on the prospect of peace with security, on the future of our Armed Forces, on the industry which supports them, and on our continued prosperity and way of life. Not all these decisions will be made in Washington. What happens as a result of decisions made in Washington is a matter for the aviation industry and its technology.

We have had for some years an expanding and prosperous economy. It will continue to expand and prosper. But there is a limit to the permissible amount of military spending, and we have already just about come to that limit. Our task is to see that within that limit we generate the military force to keep the peace and to preserve freedom in the world.

The United States needs sufficient nuclear striking power—well dispersed and well diversified—but we need a clear-headed rational appraisal of *how much* nuclear striking power.

The United States needs to maintain the best strategic warning against attack—but not so much defense that we will pass the point of diminishing returns.

Versatile forces that contribute to offensive requirements across the board, and defensive requirements as well, give us significant gains in economy and efficiency.

Under this Administration we have described the limit in a level military budget. We have avoided "feast or famine" financing and have sought instead to establish steady long-range programs—programs on which the Armed Services and industry could base steady and orderly progress. In the main, and until recently, we have been successful.

However, now we are faced with an inflation of costs, almost without precedent. In military procurement, it is three inflations combined: the in-

**The complete Dinner Address appears in the *Proceedings* of the National Naval Aviation Meeting.**

flation of dollars, which results in less for our money; the inflation of size and complexity; and the inflation of ideas. These three will work together to rob us of the forces we know we need for national security, *if* we do not understand them and deal with them effectively.

And the first step in understanding is to recognize the "object of the ball game" in the design of our military forces. The object is simply this: to provide military force sufficient to ensure, working with our Allies, the peace and security of the free world. For this we need forces sufficient to support our policy in cold war, sufficient to win decisively in hot but limited war, and sufficient to make it unthinkable for any aggressor to resort to thermonuclear war. This much we need—no more, no less.

Our national position on disarmament has been made clear. We have consistently taken the lead in seeking a safeguarded agreement. We have made proposals that would bring under control the nuclear threat, control conventional armaments—and outer space objects, and create safeguards against armed attack. We are seeking today agreements on a safeguarded first stage. But until such agreements have been made, it is vital to the security of the free world that we maintain our military posture.

(*Continued on page 85*)

# ... *From a Distinguished Past*

*A model of the Navy's first seaplane is displayed by Fred Verville to Secretary Gates, as Paul Garber, Rear Adm. G. B. H. Hall, Bill Mollering, and Vice-Adm. Alfred M. Pride look on.*

*A solution to the problem of devising a form of construction to maintain contour and smoothness yet effectively use material with weight to meet strength and stiffness requirements.*

# Some Notes on Sandwich Design for Minimum Weight as Applied to Airplane Wings

J. G. Willis
Convair, A Division of General Dynamics Corporation

THESE NOTES COVER some elementary considerations effecting the preliminary design of multispar box construction for minimum weight.

Simple equations can be developed for optimum proportions, particularly when the box is pressurized, as required by fuel tanks.

The development of cellular sandwich type of paneling, using hexcel or stiffened square-cell cores of remarkably low density to give continuous support and stability to the outer skins, has provided the engineer with a rather unique material for aircraft structural design.

Although many ingenious attempts have been made to offer alternative types of cores, so far nothing can compete with the cellular construction for uniform stiffness, continuous skin support, weight, appearance, and simplicity of construction.

Sandwich construction appears to offer the following advantages, particularly for the design of wings: aerodynamic smoothness, increased resistance to thermal buckling, and possibility of working up to compressive yield of skin material.

From the weight point of view, the utmost care is needed in detail design to prevent the overall weight from exceeding that of other forms of construction. To put this fact another way, it is comparatively easy to attain high allowable compressive stresses in individual test panels, but the accumulation of weight during the process of detail design and fabrication can, and invariably does, seriously reduce the overall strength/weight ratio expected.

Our problem is to devise a form of construction that accurately maintains contour and smoothness, and that effectively uses the structural material and associated weight to meet strength and stiffness requirements.

For a wing, which is the primary consideration here, these conditions are generally met by multiple spanwise spars with a minimum of ribs or bulkheads. The arrangement or orientation of these spars is important from the stiffness point of view, at least in delta-type plan forms where considerable root chord is available.

A little thought will show that for a given control force or shear, normal to the wing trailing edge, maximum stiffness is improved when the shear members slope forward; this slope may be in the region of 30° depending on the wing section or trailing-edge taper. Obviously, this applies only from the trailing edge forward to the maximum depth of the wing.

If the sandwich material is to be used efficiently, it is apparent that the spar-cap areas should be quite small. However, if fuel is to be carried in the wing, then the trend toward increasing altitudes and temperatures requires considerable increase in tank pressure, which makes sealing problems more difficult, necessitating substantial spar-cap areas for practical designs. Since spar-cap areas depend to a large extent on the basic form of sandwich adopted, it appears advisable as a first step to assume that the sandwich takes the full end-load from wing bending and estimate skin thicknesses accordingly.

Provided the skin and core are intelligently selected in relation to panel size, it is possible to work near to the yield of the material in compression.

Taking a representative chordwise slice of unit width, as in Fig. 1, we can write:

$$W_c = 4t\rho_s + 2d\rho_c + (A/P)\rho_s \qquad (1)$$

where

$W_c$ = weight per inch span, per inch chord
$\rho_s$ = density of skin and spar material
$\rho_c$ = density of core
$d$ = thickness of sandwich
$t$ = skin thickness
$A$ = cross-sectional area of spars, and local sandwich attachment
$P$ = spar pitch
$K$ = $d/t$

**The author's position is Design Specialist.**
**The opinions expressed are not necessarily those of Convair.**

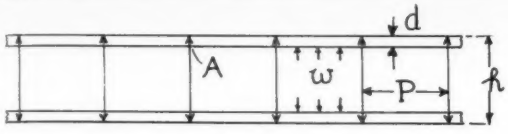



FIG. 1.

For permissible deflection between spars of $\delta$ and a pressure differential of $\omega$, we can write for a simply supported beam:

$$d = P^2\sqrt{(\omega/\delta)/40Et} = P^2/D$$

then

$$W_c = 4t\rho_s + (2P^2\rho_c/D) + (A/P)\rho_s \qquad (2)$$

on differentiating

$$P_0 = \sqrt[3]{AD\rho_s/4\rho_c} \qquad (3)$$

for minimum weight.

These proportions must be checked against those required to prevent general panel instability for panels in compression.

Since the variable $\omega/\delta$ has considerable influence on the $d/t$ ratio, it is desirable to estimate optimum values of $d/t$ for specific conditions and for weight comparisons.

For constant $P$ and unit width, we can write

$$W = 2t\rho_s + tK\rho_c$$

For stiffness, $t \propto K^{-2/3}$
For bending, $t \propto K^{-1/2}$
Bending buckling, $t \propto K^{-1/4}$

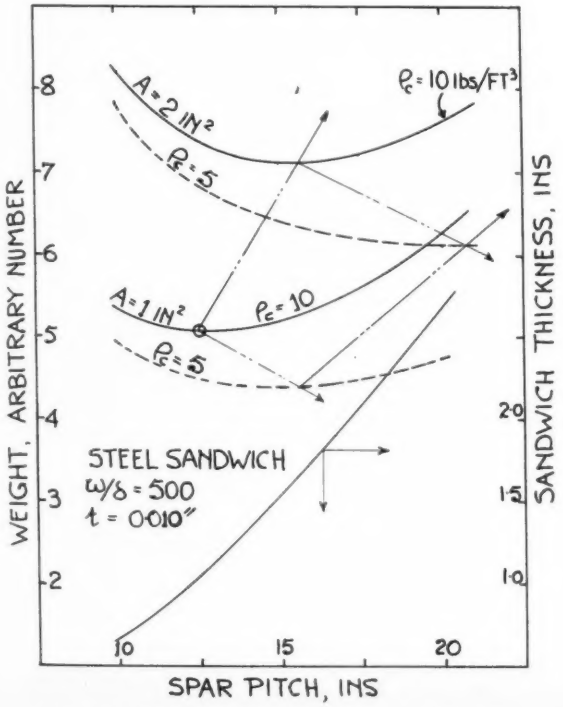



FIG. 2. Effect of varying spar area or core density.

FIG. 3. Spanwise panel under combined end-load and norma pressure.

The latter case covers working near the buckling range of the skin. On substituting these values in Eq. 3, differentiating and equating to zero for minimum weight we get, $4\rho_s/\rho_c$, $2\rho_s/\rho_s$, and $(2/3)(\rho_s/\rho_c)$, respectively, for optimum values of $d/t$. Because of the wide variation in optimum values, which are in the ratio 6:3:1, it will be evident that a compromise on $d/t$ will usually be necessary to suit any particular combination of conditions.

It is, therefore, instructive to illustrate the effects on weight of varying the core density, and the spar areas, versus spar pitch for constant $\omega/\delta$ (see Fig. 2).

This graph also indicates that some slight departure from optimum pitch $P_0$ is probably justified in the interests of increasing fuel capacity—i.e., from reduction of $d$.

It will be apparent that as a first step the skin thickness of the sandwich would be designed on the assumption that the panel would work up to the full allowable stress of the material. At the same time, it is also evident that the addition of the spar-cap areas should permit a reduced skin thickness compatible with a reduced average stress ratio. If the compressive load is assumed to be taken only by the skins as a first estimate, then, at stress $\sigma_s$, upon adding the spar-cap areas $A_c$, the average stress is reduced to $\eta\sigma_s$, or

$$\eta = t_1/[t_2 + (A_c/2P)] \qquad (4)$$

Also, upon letting $\eta$ vary as $(t_2/t_1)^2 = S^2$, to compensate, for example, for possible local buckling of skins with the type of core being used, we have

$$S^3 + S^2(A_c/2t_1P) - 1.0 = 0 \qquad (5)$$

from which $S$ can be found, and hence $\eta$ and $t_2$. However, the reduced $t_2$ is permissible only if $d$ is increased to $d\sqrt{t_1/t_2}$ in order to maintain design deflection $\delta$. Obviously, this is a rough approximation and a more detailed study is necessary to take into account the stress distribution across the panels from combined loads involved.

On substituting relative values for a steel sandwich, the designer sees that $t$ may be reduced from 20 per cent to 30 per cent, yet $\eta$ is still no more than about 50 per cent to 60 per cent. Evidently, the value of $(A/2t_1P)$ should be as small as possible. The trend to larger values of this ratio in steel and the like completely ruins the effectiveness of sandwich construction from the strength/weight ratio point of view.

On the other hand, one might add that secondary stresses are likely to be severe and unpredictable, especially from thermal effects, and there is some justification for working at a reduced stress. For example (Fig. 3), if one considers a long narrow spanwise panel

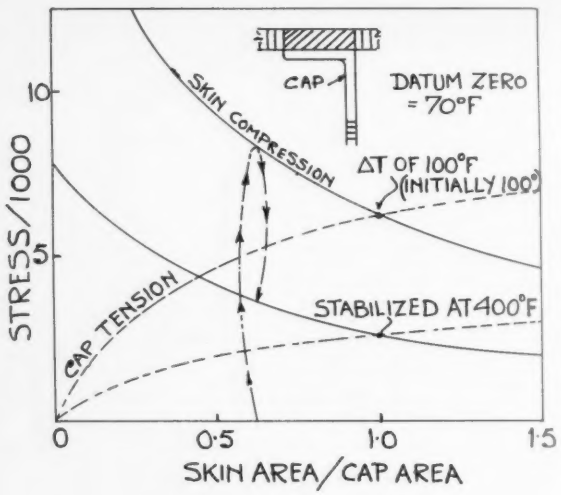



FIG. 4. Stress due to $\Delta T = 100°F$.

under combined end-load and normal pressure, designed to stress $\sigma$, then in a region of chordwise constraint at a rib or bulkhead, it is seen that the additional effects of thermal lag can substantially increase the end loading conditions of the panel.

A rough approximation to the additional deflection due to $\Delta T°$ after some allowance for constant at the spars is

$$\delta_\theta = (P/2)\sqrt{\alpha \cdot \Delta T}$$

where $\alpha$ is the coefficient of expansion for skin material. Then, if $\sigma_p$ is to be the design compressive stress and $\sigma_m$ the maximum permissible, this ratio becomes

$$\sigma_p/\sigma_m = 1/[1 + (2\delta_T/d)]$$

where $\delta_T$ here is equal to $(\delta_\theta + \delta)$. This value could be compared to $\eta$ from Eq. 5. For a 3/4-in. steel skinned panel, at a $\Delta T$ of 100°F., this would indicate a reduction of over 30 per cent on the design allowable stress.

The severity of thermal lag depends on the construction adopted, the thermal resistance to inner members, and the rate of heat input or acceleration to high Mach Numbers.

It is axiomatic that if an interceptor is to operate successfully, some form of accelerating boost additional to the basic power for normal sustained maximum speed becomes desirable or even essential to make interception feasible at its stated Mach Number capability. It would appear, therefore, that we can expect increasingly severe thermal stress problems, with temperature differentials approaching several hundred degrees, which may well prove to be the most critical factor in design.

An indication of the stresses that could be induced in stainless steel skins attached to titanium structure is shown in Fig. 4 for a temperature difference of 100°F. Stresses will, of course, increase in proportion to increasing temperature differential. They would be much higher for steel on steel, and somewhat lower for titanium on titanium.

Insulation should always be a useful palliative, especially for the one-shot type of missile. For airplanes, however, we require a much more durable and practical covering, such that its properties may also require it to work at the same stress level as the structure. No doubt, the weight of such a covering merely as insulation would be prohibitive and costly.

Thus we begin to visualize a rather unique material, at present nonexistent, which is really a basic structural material capable of withstanding maximum temperatures for long periods—in short, improved high-temperature materials, not insulation, as such. The heat flow to the interior of the wing or fuselage should then be slowed down by suitable design methods such as honeycomb sandwich construction. Needless to say, such new materials need not necessarily be of metal.

## Comparison With Full Core Section

Inevitably, increasing values of $\omega/\delta$ will turn attention to the possibility of full depth cores, so an estimate of the break-even point on weight is desirable.

Assuming thickness of skin will vary inversely as the depth of the box $h$, let

$$t_1/t_2 = h_2/h_1 = H^2 \tag{6}$$

Now Eq. (2) can be written for the sandwich box as

$$W_c = (4t_1\rho_s/H^2) + (2P^2\rho_c H/D) + (A\rho_s/P) \tag{7}$$

similarly, for the full depth core wing

$$W_c = (4t_1\rho_s/H^2) + \rho_{cc}h_1H^2 + (A\rho_s/P_c) \tag{8}$$

Here, the actual skin thickness will be twice that of the sandwich arrangement, also note that $\rho_{cc}$ and $A$ should, in general, be less than the sandwich and $P_c$ will be much greater—i.e., there will be fewer spars. It should also be noted that $A$ is assumed constant. This is because the effect of spar web weight with $H$ is relatively small over the range being considered.

Equating Eqs. (7) and (8), the break-even point on weight is obtained when

$$\rho_{cc}h_1 = (1/H^2)[(A\rho_s/P)_s - (A\rho_s/P)_F] + (2P^2\rho_c/HD) \tag{9}$$

from which the necessary full core density $\rho_{cc}$ for equal weight can be determined.

It is much more instructive, however, to plot minimum weight curves for sandwich box construction over curves for comparable full core design, as in Fig. 5.

From Eqs. (2) and (3) the locus of minimum possible weights for a given $D$ and hence $t$ are given by

$$W_{sm} = 4t\rho_s + 6(A\rho_s/4)^{2/3}(\rho_c/D)^{1/3} \tag{10}$$

and these curves are plotted on the figure. These show that for a given $\omega/\delta$ any value of $h$ to the right of the curves should be of sandwich construction and to the left, full core construction.

If the thickness of wing $h$ indicates that consideration should be given to a full core design, then from a weight point of view this can be optimized as follows:

From Eq. (8) the value of $H$ for minimum weight is found to be

$$H^2 = \sqrt{4t_1\rho_s/h_1\rho_{cc}} \qquad (11)$$

whereas the corresponding value of $H$ applied to Eq. (7) shows that skin thickness and weight would most likely increase. These trends are indicated on the figure.

From Eq. (11), note that minimum weight is achieved when

$$h/t = 2\rho_s/\rho_{cc}$$

remembering that actual skin thickness for the full core arrangement is taken as twice the thickness of the sandwich skin.

In actual detail design, the increased skin thickness may also reduce the core density compared to that used in a thin sandwich subject to developing satisfactory shear resistance.

At first sight it might be thought that storing fuel in a full core wing would be nearly impossible. It is, however, a matter of practical ingenuity in detail design.

Considering the potential wing volume for fuel, if the proportions of a wing box are arrived at by a sandwich construction basis in order to obtain a desired wing volume $V_s$, then, since the fractional volume loss will be approximately $2d/h$, compared to $\rho_c/\rho_m$ for a solid core design ($\rho_m$ = core material density), it will be apparent that the wing thickness chord ratio could have been reduced to

$$\{[1 - (2d/h)]/[1 - (\rho_c/\rho_m)]\}(t/c)$$

for the same volume $V_s$.

Alternatively, and what is probably of greater interest, $V_s$ could be increased to

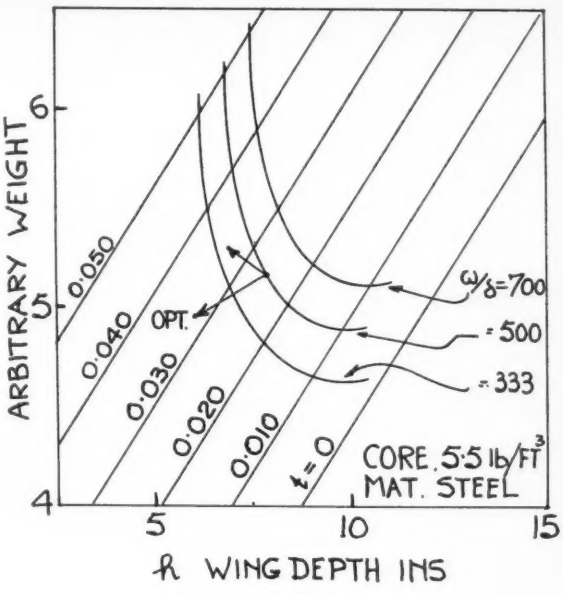



FIG. 5.

$$\{[(1 - (\rho_c/\rho_m)]/[1 - (2d/h)]\}V_s$$

On substituting relative values, the former could mean a reduction in wing thickness of up to about 10 per cent or, for the latter requirement, a possible increase in volume of about 12 per cent.

In summary, the indication is fairly clear that the present trend to higher pressures in integral wing tanks in conjunction with very thin wings will in many cases justify the adoption of some form of full depth core wing construction. Where such is the case, the additional advantages are too obvious to need discussion.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*"Doppler principles can be used to determine the velocity vector of an aircraft and its components relative to the earth."*

# Problems in Doppler Navigation

Floyd T. Wimberly and Craig L. Crowell
Raytheon Manufacturing Company

## Introduction

### *Physics of the Doppler Principle*

The apparent change in pitch of a sound to an observer when either the source of the sound or the observer move with respect to one another is an old familiar demonstration of the Doppler effect. The change in pitch of a locomotive bell or whistle as it passes an observer demonstrates the case of the moving source; the same sort of phenomenon is noticed by the observer riding in the train as he listens to the stationary warning bell at a railroad crossing. The apparent change in wavelength of light received from the stars has been used to measure the speed with which the distance between the earth and a star is changing. Traffic officers patrolling the highway now employ instruments which, by measuring the apparent change in frequency (or wavelength) of radio waves reflected from passing vehicles, enable them to help motorists obey the speed limits. All of these observable results, whether they be obtained through precisely the same physical phenomena or not, have been labeled the Doppler effect—the apparent change in frequency or wavelength of a signal when the source and observer are approaching or receding.

In the case of the traffic officer's instrument, there is one major noticeable difference—since the target vehicle would, in the role of an observer, be able to receive a signal higher in frequency than that transmitted by the officer's instrument and reflect or reradiate this received signal back to the instrument or source, it plays the role of both moving observer and moving source. The difference in frequency received by the instrument is, for all practical purposes, a function of twice the relative speed between the instrument and the vehicle.

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### *The Doppler Effect as Applied to Radar Navigation*

For all practical purposes, it can be shown that the difference in frequency between a transmitted radio signal and the signal received back at the transmitter after reflection from a target (when there is motion between the two) is a function only of the transmitted frequency and the relative speed along the line of sight joining the transmitter and the target. If a radio transmitter-receiver is mounted in an aircraft and a directional antenna is pointed at the ground over which the aircraft is flying, a difference frequency will exist between the transmitted and received signals. This difference, or Doppler frequency, is a function of the transmitter frequency, the velocity of the aircraft, and the angle between the aircraft velocity vector and the antenna beam. Equipments which utilize these principles for the solution of navigational problems are called Doppler navigators or Doppler radars.

## Application of Doppler Information to the Aircraft Navigation Problem

The difference frequency which exists because of the Doppler effect (hereafter called Doppler frequency) is a function only of the transmitted frequency and the component of aircraft velocity along the antenna beam axis. However, a simple single beam radar cannot, by itself, determine all the factors required to solve the navigation problem. For instance, a simple single antenna radar system which detects only the component of aircraft velocity along the antenna axis cannot distinguish between the velocity components due to vertical, lateral, and longitudinal velocities of the aircraft; it can indicate only the component of the total aircraft velocity along the antenna beam. By utilizing more than one antenna beam more information may be obtained.

Three unknowns contribute to the total aircraft velocity vector, the longitudinal, lateral, and vertical components. Most often, these three velocities contribute simultaneously. A measure of two of these

velocities, the longitudinal and lateral, are minimum requirements for a navigation system to determine the rate of translation of an aircraft over the surface of the earth. The third or vertical velocity of the aircraft is also important but is not an absolute necessity in a simple navigation system that merely provides ground speed and drift angle. A pilot may have considerable difficulty discerning whether his destination is right, left, in front, or behind. He is reasonably assured, however, with a bare minimum of instrumentation, that his destination is somewhere below the aircraft. It is true during conditions of poor visibility that there may be some concern in this regard, but present-day radar altimeters present the necessary information and could indicate the rate of change of altitude if required to do so. Doppler radars can, and some do, solve the vertical velocity of the aircraft, but three separate and independent measurements of velocity are required to accomplish this.

The simplest means of measuring longitudinal and transverse velocities would be to orient two antenna beams so that their axes are at right angles in the horizontal plane of the aircraft and with one beam directed along the longitudinal axis of the aircraft. If this were practical, the individual antennas would, in normal flight, measure the forward and sideward velocities of the aircraft. However, if this configuration were attempted, the narrow antenna beams required for reasonably accurate measurement of the two velocities would not illuminate the surface of the earth below the aircraft but would transmit energy into the atmosphere and receive no Doppler information. It is thus necessary to depress the antennas from the horizontal plane, and when this is done, both antennas measure a component of the vertical velocity in addition to measuring the desired velocity. Other factors usually lead to an antenna configuration differing from the simple one described above.

Since the contribution of vertical velocity of the aircraft will appear in the individual Doppler frequencies when the antennas are depressed from the horizontal, it becomes necessary to remove this component by taking enough independent measurements of velocity for the solution of an equation with three unknowns. This can be accomplished entirely with Doppler techniques by utilizing a minimum of three antenna beams. It can also be accomplished with the use of two antennas and a separate source of velocity measurement such as vertical velocity obtained from an altimeter. Four beams are sometimes used but provide redundant information which contributes little, if anything, to the solutions. The measurements of the three (or two) bits of velocity information are not required simultaneously but within a period of time limited only by the maximum rate of change of the total velocity vector of the aircraft and the intended use of the velocity information.

If three beams are utilized and are directed as shown in Fig. 1, the equations that must be solved by the navigation system in obtaining the aircraft component

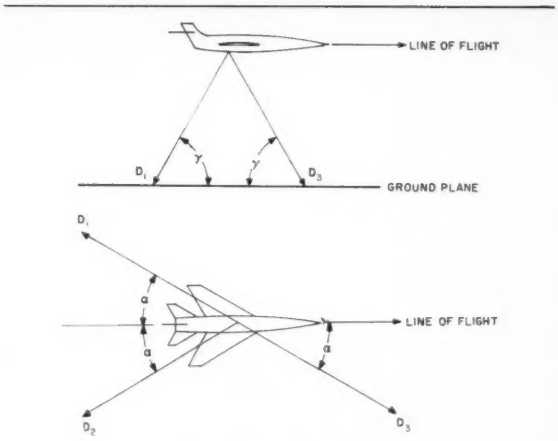


FIG. 1. Doppler radar antenna beam geometry. (a) *Top:* Vertical plane. (b) *Bottom:* Horizontal plane.

velocities from the antenna velocities or Dopplers are:

Longitudinal velocity

$$V_L = (|D_2| - |D_3|)\lambda/4 \cos \alpha \cos \gamma$$

Transverse velocity

$$V_T = (|D_2| - |D_1|)\lambda/4 \sin \alpha \cos \gamma$$

Normal velocity

$$V_N = (|D_1| + |D_3|)\lambda/4 \sin \gamma$$

where $|D_1|$, $|D_2|$, and $|D_3|$ are the absolute values of the Doppler frequencies along the respective antenna beams as shown in the figure, $\lambda$ is the wavelength of the transmitted energy, $\alpha$ is the angle of each beam with respect to the longitudinal axis of the aircraft in a horizontal plane, and $\gamma$ is the angle of each antenna beam with respect to this plane.

Once the longitudinal, transverse, and vertical (if used) velocities are known, the major needs of a navigation system are available. To complete the navigator function it is only necessary to resolve the aircraft velocities into the particular coordinate system desired. The simplest navigator need only resolve the aircraft longitudinal and transverse velocities into a velocity vector along the ground. These data are essentially the ground track and speed of the aircraft and could be displayed on a simple instrument indicating the actual travel along the ground. By comparing these data with the air-speed indicator, the wind speed and direction could be approximated, and by simple dead-reckoning techniques, the pilot may determine the heading required to reach his destination and how long he must fly to get there.

A more elaborate navigator can provide an indicator which displays the position of the aircraft in the desired coordinate system. In this type of equipment, it is not only necessary to resolve the aircraft velocity vector into forward and sideward speeds along the ground, but it must convert these speeds into North-South and East-West coordinates (or into any other coordinate system, depending on the type of heading reference used) and integrate these velocities to deter-

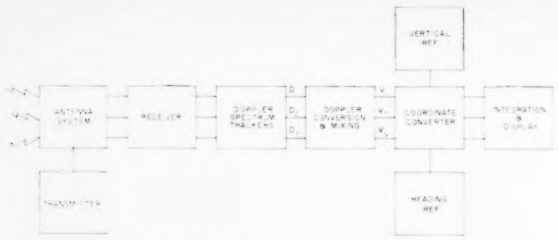


FIG. 2. Simplied block diagram of a Doppler navigator.

mine present position. This leads to a basic limitation of Doppler navigators—the system is "tied to the earth" and is capable only of determining the relative velocity components of the vehicle and cannot by itself relate these components to positions or directions with respect to the earth.

In the nature of a summary the following review is made. Doppler principles can be used to determine the velocity vector and its components relative to the earth. These data can be used with other data available in most aircraft to: (1) determine speed and direction over the surface of the earth, (2) determine position in the desired coordinate system (including altitude), and (3) determine speed and direction of the wind.

## DOPPLER NAVIGATION SYSTEMS CONSIDERATIONS AND TECHNIQUES

The following equipment is required to utilize the Doppler principles in navigation:

(1) A source of R.F. Power.
(2) An antenna system.
(3) A receiving system.
(4) Equipment to determine the Doppler frequency and to convert it to the desired velocity information and form.
(5) Equipment to convert the aircraft velocities into the desired navigational coordinate system.
(6) An output system which converts the information to the desired form whether it be visual for the pilot or electrical, or hydraulic for the autopilot or any other use.

A very basic block diagram of a Doppler navigation system is presented in Fig. 2.

The choice of equipment required and the particular techniques used are affected heavily by the type of aircraft in which it is desired to install the navigator and the ultimate results required of the system.

Many factors must be considered in the selection of an R.F. Power Source (or transmitter). A transmitter is chosen which is in the microwave region since for aircraft application usually a bare minimum of skin area is available for installation of antennas and, since narrow antenna beams are desired, the higher the frequency of the transmitter the narrower the antenna beams for the same aperture area. There are other important factors which affect the selection of the transmitter, such as the variation of reflection properties of the land and water and the variation of weather effects on propagation for different frequencies.

Not the least of the problems facing the designer of a Doppler navigator system is that of selecting a transmitter which will operate satisfactorily under the adverse environmental conditions prevalent in most aircraft, since the Doppler frequency is a function not only of the aircraft velocity but also of the absolute frequency of the transmitter.

For the optimum system the designer must also select a transmitter with sufficient power to allow the system to operate satisfactorily at the maximum altitude the aircraft is expected to attain. Since the return signals for Doppler radars are reduced by 6 db. each time the aircraft altitude is doubled—the received power varies inversely with the square of the altitude since the target fills the antenna beam width—and since microwave power is costly in terms of the weight and special techniques required in air-borne high voltage supplies, the transmitter should be chosen for sufficient but not excessive power output.

Either pulse or CW transmission techniques may be employed by the radars associated with Doppler navigators, the basic difference between the two techniques being in the method used for duplexing transmitter and receiver functions. Pulse radars transmit microwave energy in bursts and receive reflected energy between these bursts. Thus the receiver is effectively turned off during transmitter operation and operates on reflected energy only between transmitted pulses. Duplexing is thereby accomplished in a time sense. The disadvantages of pulse transmission lie in the complexity required to make the system optimum for navigational purposes.

CW radar systems transmit and receive microwave energy continuously and simultaneously. Receiver-transmitter duplexing is accomplished in a space sense with most systems—i.e., separate receiving and transmitting antenna systems are used. Obviously, for equivalent antenna beam widths, the CW system will therefore require greater aperture area in aircraft than the comparable pulse system. However, the simplicity of the CW system makes it very attractive when all factors are considered and compared with the relative complexity of the pulse system. Despite adverse publicity, a CW system possessing equal average power and antenna gain will yield the same range as a pulse system, especially when low transmitter power is used as in navigator Doppler radars.

The severely limited available aperture area is one of the many factors affecting the design of an antenna system for Doppler navigator radars. As outlined elsewhere in this paper, the greater the aperture the more accurate the navigator.

The antenna system can either be fixed to the air frame or it can be stabilized to the vertical and/or any particular velocity component or direction. With a vertically stabilized antenna, the navigator can operate satisfactorily over a greater range of aircraft pitch

and roll than could an antenna mounted rigidly to the aircraft. Stabilized antennas generally require larger apertures, however. Comparing the complexity, power requirements, and weight of the stabilized antenna with that of stabilizing the electrical equivalent of the aircraft component velocity vectors, the latter generally appears more attractive for aircraft application. The same accuracy can be obtained with either technique.

The receiver selected for the radar can take many forms and either homodyne (zero frequency IF) or IF receivers can be, and are, applied in present equipments for fixed-wing aircraft. The use of the IF receiver results in lower noise figures and can result in the use of lower transmitter power, but the selection of course depends upon the particular application. An IF receiver is necessary when applied to helicopters, however, since Doppler frequency sense must be retained (the velocity vectors can be in any direction) and sense is lost in a simple homodyne system.

In listing the problems associated with receivers for Doppler radars it could be said that they are common to all air-borne microwave equipment. There is a need for improvement in receivers, especially in microwave mixers. Also, there are not available, today, local oscillators which are entirely satisfactory for use in Doppler radars when applied to a variety of aircraft types.

Once the significant Doppler frequencies have been detected and amplified to a satisfactory level, they can be converted to a convenient form to permit the computation of the desired information. The longitudinal, transverse, and normal velocities of the aircraft can be determined, or the total velocity vector can be determined and the navigational problem solved by means common to the navigator field. The Doppler navigator does offer an advantage over other velocity sensing elements in that the data are obtained normally in the frequency domain and as such are like FM radio in comparison to AM radio—less subject to man-made and natural electrical disturbances.

## Problems and Errors Associated With Doppler Navigation

The methods and techniques utilized in solving the navigation problem by integrating the aircraft orthogonal velocity components are similar to systems other than Doppler navigators. This discussion, therefore, is concerned primarily with the front end, or radar, and its function of obtaining Doppler derived aircraft velocity components.

Inherent difficulties encountered in obtaining precise Doppler velocity data are considered. Problems associated with aircraft, both from the installation and application standpoint, are also discussed.

### *Problems Unique to Particular Aircraft Types*

In fixed-wing aircraft, the longitudinal velocity component determines the sign of Doppler frequency in all antenna beams since its magnitude is considerably larger, under almost every condition, than the magnitude of either the transverse or vertical velocity components. The minimum Doppler frequency encountered during adverse flight attitude conditions (severe angles of attack for instance), maximum and minimum operational velocities, rates and magnitudes of perturbation, and accuracy and altitude requirements are items that must be considered in the design of a Doppler radar for a particular type of fixed-wing aircraft.

Helicopters present an entirely different set of problems, however. The three orthogonal velocity components of helicopters may be in any direction and simultaneously comparable in magnitude. In fact all the velocities might be zero during a hovering condition. This presents a unique set of problems to a Doppler navigator in that Doppler frequency sense must be retained and operation to and through zero Doppler frequency must be realized.

### *Sea Flow*

It is a known phenomenon that various parts of the sea can be in continuous motion, such as the flow evidenced in the Gulf Stream and the Japanese Current. The motion of the water in these cases results in measurement errors of aircraft ground speed with a Doppler radar system. The sign of the error ($\pm$) is determined by the direction of the aircraft velocity vector in relation to the direction of the flow of the water. Since the direction and velocity of most ocean currents are known, it is possible manually and automatically to provide the proper correction factors to the aircraft Doppler velocity information when operation is desired in the area of these ocean currents.

A sustained wind will also result in surface motion of the water particles, thus resulting in an error similar to that occurring when flying over ocean currents. Generally speaking winds are of random direction, and long, overwater flights tend to average out the effect due to the surface motion. Also, since wind direction, velocity, and duration may be forecast for any particular part of the earth, it is possible to calculate before a flight the total error in the Doppler data (both direction and magnitude) and allow for the proper correction factors.

### *Weather Effects*

An important consideration in the design of a Doppler system, primarily in the selection of the microwave frequency, is the effect of precipitation on the Doppler signal. Back scattering and attenuation of the microwave energy due to rain, snow, etc., can not only reduce the sensitivity of the radar but can reduce the precision of velocity measurement. One must therefore not go overboard in attempting to satisfy beamwidth, antenna aperture, lightweight, and small size desires by increasing microwave frequency to the point where overall operation deteriorates because of inclement weather conditions.

*Microwave Frequency*

As outlined previously the Doppler frequency shift is proportional to the microwave frequency being transmitted. For an accurate measure of antenna velocities in Doppler navigator radars it is, therefore, important that the transmitter frequency remain constant within certain long-term limits. The percentage variation of the microwave frequency from the calibration value is reflected in the same percentage error in measurement of antenna velocity.

Short-term variation in the transmitter frequency is reflected in a broadening of the Doppler spectrum and is of special concern at the higher altitudes. Frequency modulation of the transmitter must therefore be minimized. A.F.C. systems using stabilized cavities as the reference perform adequately to reduce errors due to transmitter frequency variation, both long- and short-term, to negligible quantities.

Selection of the microwave frequency is dependent on a number of factors such as: availability of a suitable microwave generator, weather effects, size, weight, input power, available antenna apertures vs. beamwidth required, reflection coefficients, and F.C.C. frequency allocations.

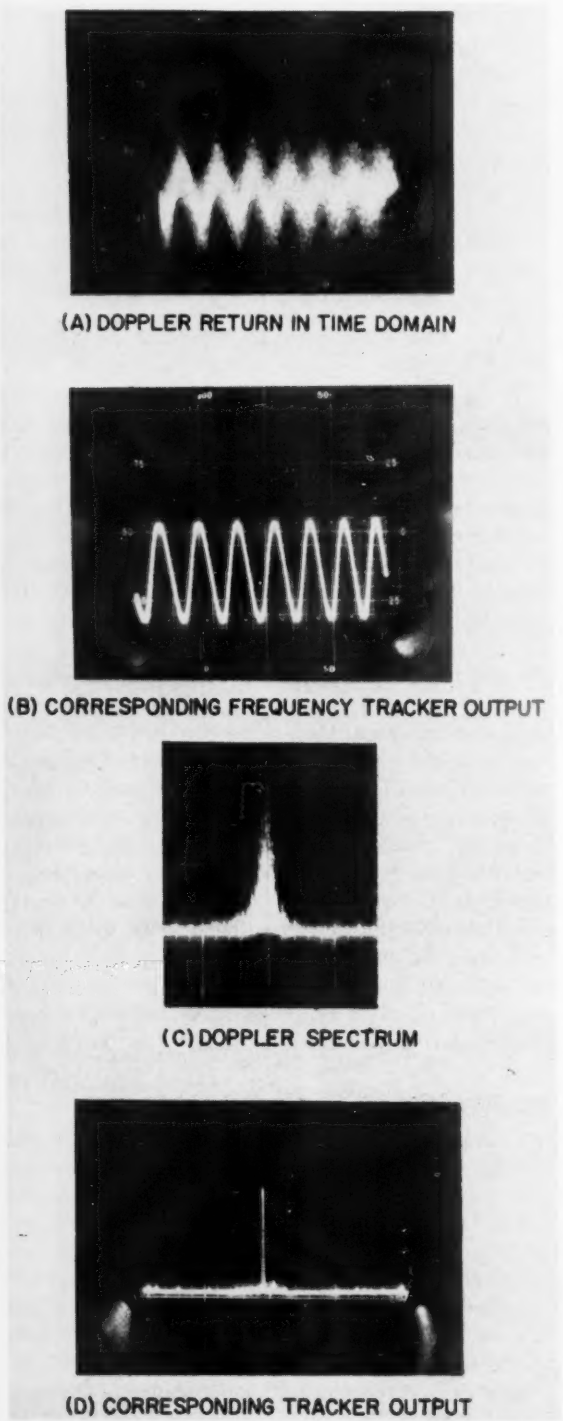
(A) DOPPLER RETURN IN TIME DOMAIN
(B) CORRESPONDING FREQUENCY TRACKER OUTPUT
(C) DOPPLER SPECTRUM
(D) CORRESPONDING TRACKER OUTPUT

FIG. 3. Characteristic wave forms and spectra for Doppler navigators.

*Antenna Considerations*

It is important to the accuracy of a Doppler navigator radar that the angular positions of all the antenna beams are precisely known with respect to each other and that the cluster of beams are aligned accurately to the earth reference system in the aircraft. The important calibration and boresight angles of a three beam Doppler radar system are shown in Fig. 1. The Doppler system may be ground calibrated if the angles $\gamma$ and $\alpha$ shown in the figure are known. In addition, these angles must remain constant with environment and time for continued system accuracy.

Some of the antenna characteristics which are important to a Doppler navigator are listed below.

(1) Narrow beamwidths are desirable to obtain minimum terrain bias errors, minimum signal fluctuations, and maximum radar sensitivity (gain).

(2) Small size, light weight, and efficient use of available aperture is necessary to be practical for use in aircraft.

(3) The antenna system must be structurally sound to withstand aircraft shock and vibration environments without loss of precision.

*Signal Fluctuations*

Because a finite antenna beamwidth must be employed in Doppler radars used for aircraft navigation purposes, the resulting Doppler signal consists of a band of frequencies generally gaussian in shape. Because of these signal characteristics (Fig. 3), the instantaneous frequency produced by the Doppler system fluctuates quite widely from that frequency representative of the power center of the spectrum and/or antenna beam. The amount of fluctuation of the Doppler spectrum is determined by the spectrum bandwidth which in turn is proportional to the effective antenna beamwidth.

Theoretically a sufficiently narrow antenna beamwidth could be produced to limit the errors arising from signal fluctuations to insignificant levels. How-

ever, the design of the antenna system to accomplish this would require more aperture area than the aircraft designer could permit. When a stalemate is reached on the available area, the usual method of resolving the problem is to sacrifice antenna beamwidth and provide more filtering of the output data which does, indeed, reduce fluctuation errors. This cannot be accomplished, however, without an increase in acceleration errors arising from the inability of the system to respond rapidly to changing input velocity data.

### *Doppler Data Processing*

Mixing antenna or Doppler velocities in the proper manner to obtain the longitudinal, transverse, and normal aircraft velocities is usually accomplished in the process of converting the Doppler frequency to the form required by the particular type of navigation computer. Mixing at broadband microwave, IF, or Doppler frequencies may also be accomplished, but this results in sensitivity degradation.

The mixing and signal form transformation may be accomplished in a variety of ways with high precision, and is not generally a determining factor in the overall accuracy of the system.

If the antenna system is rigidly fixed to the air frame, the aircraft component velocity data must be resolved to the ground coordinate system for use by the navigation computer. Again, the method of transformation is involved with computer type whether the reference information from the vertical and heading references is analog, mechanical, or digital in character.

### *Earth References and Navigation Correction Factors*

In order to compute present position from the Doppler derived velocities, it is first necessary that the component velocities be transformed to an earth coordinate system. This transformation is usually accomplished in two steps. First, either the antenna system is stabilized with respect to the vertical, or the velocity data are corrected for aircraft pitch and roll, both schemes using information from a vertical reference system. The second step is to transform the stabilized velocity components into North-South and East-West velocities by using the true heading of the aircraft as the reference. Converse to errors in the vertical, Doppler navigators are characteristically dependent on errors in azimuth or heading reference systems. A Doppler navigator can never be more accurate than the accuracy of the associated heading reference.

If a flux gate compass is used as the heading reference for Doppler navigators, compensation for magnetic variation must be included in the system. The compensation may be accomplished either automatically or manually.

A Doppler system does not measure the velocity along the earth's surface but rather the velocity with respect to scatterers on the surface. As a consequence, an altitude correction is usually included to correct for this phenomenon. Since the resulting error is of small magnitude being proportional to the ratio of the altitude to the radius of the earth, a small ratio considering present aircraft capabilities, the accuracy of correction need not be particularly precise.

Other corrections are also usually included in Doppler navigation systems to compensate for such things as the oblateness of the earth and the convergence of the lines of longitude.

## Conclusion

The technique of navigating aircraft using Doppler principles at microwaves has progressed appreciably since development began in this country under Air Force (WADC) cognizance at the General Precision Laboratories approximately 10 years ago. At the present time, under the direction of both the Air Force Weapons Guidance Laboratory (WADC) and the Navy Bureau of Aeronautics, the Raytheon Manufacturing Company, Laboratory for Electronics, General Precision Laboratory, General Electric, Sander's Associates, and Ryan Aeronautical are designing, developing, and producing Doppler navigator equipment for a variety of aircraft types. The Doppler navigator has proved to be a useful and successful tool as applied to aircraft.

The industry at present is continuing research and development in attempting to apply new techniques to the age-old Doppler principle to produce more accurate, lighter, and smaller Doppler navigation systems.

**NATIONAL NAVAL AVIATION MEETING PROCEEDINGS**

The *Proceedings* of the Naval meeting (held in San Diego, Calif., August 5–10, 1957) will contain all *unclassified* papers presented at the meeting and will be available in November.

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# LIQUID ROCKET PROPELLANTS

## Is There an Energy Limit?

*Liquid rocket propellants are discussed from a chemical point of view, employing the specific impulse designation, a parameter determined by rocket combustion temperature and exhaust gas molecular weight.*

Application of the so-called high-energy liquid fuels and high-energy liquid oxidizers to power plants based on the jet propulsion principle is receiving the increasing interest and attention of rocket propellant chemists and power-plant engineers universally. The aspect of substantially increased—as much as 50 per cent—energy per lb. of propellant load or per cu.ft. of propellant tankage over today's propellants has whetted scientific appetites and justified probing the field of high-energy chemicals to determine the gains and problems of these chemicals. This paper will discuss chemical rocket propellants so that the following five questions will be, in part at least, answered or recalled to the minds of this audience for additional deliberation.

(1) What are the explicit advantages to be derived from the use of high-energy propellants in jet-propulsion devices, particularly rocket engines?

(2) Where do the liquid chemical rocket propellant systems available to power-plant engineers today fit in a rocket propellant energy listing?

(3) What higher values of energy than those now obtainable can we hope to achieve from molecular, self-energizing systems?

(4) What may be the fundamental obstacles to development and application of these upper-limit chemical systems?

(5) What will the chemical constituents of future high-energy chemical systems probably be?

By confining the paper to molecular systems and bond energies, we can place outside the discussion those more visionary power plants which derive their energy from nuclear fission or fusion, ionic, free radical, solar, and any other energy process not directly associated with chemical bond energy.

The keystone equation in rocket-propellant relationships is the mathematical expression of specific impulse, a term which describes the particular propellant system under discussion (see Fig. 1). Units of specific impulse are pounds per pound per second. Specific impulse of any fuel and oxidizer mixture is defined as the pounds of thrust obtained from the reaction of a pound of that mixture per second. For orientation, theoretical specific impulse values from molecular systems range from approximately 150 sec. to approximately 400 sec.*

How is the value of specific impulse interpreted—or more directly, what significance can be ascribed to it—by the power-plant engineer? What is the relation of specific impulse to vehicle range, to vehicle size, to pay

* Specific values are expressed for chamber pressures of 500 psia, exhaust pressures of 1 atmosphere, ideally expanded under frozen equilibrium conditions.

$$I_s = 9.797\sqrt{\frac{k}{k-1}\,\frac{T_c}{M}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]} \qquad (1)$$

$$I_s = \frac{F}{W} \qquad (2)$$

WHERE:

- $I_s$ = SPECIFIC IMPULSE (POUND/POUND/SECOND)
- $k$ = AVERAGE RATIO OF SPECIFIC HEATS. ($C_p C_v$)
- $P_e$ = EXIT PRESSURE (PSIA)
- $P_c$ = CHAMBER PRESSURE (PSIA)
- $M$ = AVERAGE MOLECULAR WEIGHT OF COMBUSTION PRODUCTS
- $T_c$ = COMBUSTION CHAMBER PRESSURE (°R)
- $F$ = THRUST (POUNDS)
- $W$ = TOTAL PROPELLANT FLOW RATE (POUNDS/SECOND)

FIG. 1. Specific impulse equation.

This work is revised and condensed from the paper of the same title presented at the Rocket Propulsion Session, IAS 25th Annual Meeting, N.Y., Jan. 28–31, 1957. The author's original work is available as IAS Preprint No. 718.

The author is Chief of Research, Rocketdyne Division.

## SPECIFIC IMPULSE AND MISSILE PERFORMANCE (GENERAL RELATIONSHIPS)

(1) VELOCITY AT BURNOUT = $I_{sg} \ln \left(\frac{W_i}{W_f}\right)$

(2) VERTICAL RANGE = $h_{bo} + KI_s \ln \left(\frac{W_i}{W_f}\right)^2$

(3) HORIZONTAL RANGE = $2S_{bo} + KI_s \ln \left(\frac{W_i}{W_f}\right)^2$

(4) PAYLOAD = $f(I_s)(W_e)(W_s)$

(5) PHYSICAL SIZE = $f(I_s)(d_{bulk})$

FIG. 2.

load, to velocity at burnout, to vertical height the vehicle can achieve? Fig. 2 lists theoretical relationships between specific impulse and these vehicle performance characteristics. Eq. 1 of Fig. 2 relates specific impulse directly to burnout velocity by equating burnout velocity to the product of the specific impulse and the natural log of the mass ratio.* Eq. 2 is a general expression associating vertical range with specific impulse. Eq. 3 equates horizontal range to specific impulse; Eq. 4 relates pay load to specific impulse; Eq. 5, impulse and size. These five equations are necessarily general and are presented here to convey the concept rather than the exact interrelation of specific impulse and performance parameters. Exact values for range, pay load, size, vertical height, etc., are, in practice, determined by detailed analysis of the power plant and vehicle and are dependent upon a series of arbitrary design choices—e.g., thrust-to-weight ratio, staging trajectory, etc. However, the expressions validly show, I believe, that in the case of these five particular parameters, increases in specific impulse will lead to increases in rocket-powered missile performance.

* Mass ratio: total weight of a rocket vehicle at take-off divided by vehicle weight at burnout.

In these first figures, the fundamental equation for rocket-propellant performance—namely, the specific-impulse equation—has been presented. It has been shown that specific impulse is a function of the combustion temperature and the molecular weight, that specific impulse is an energy expression which has been developed by the reaction of the chemicals in the combustion chamber and evidenced by the enthalpy difference between combustion and exhaust gases. It has been shown that specific impulse is directly related to missile-performance characteristics such as pay load, range, and size. And it has been shown that these performance parameters are all enhanced to a greater or lesser degree by increases in specific impulse.

There are then, indeed, performance gains to be derived from seeking and obtaining increases in specific impulse from chemical systems.

Fig. 3 lists some theoretical values for specific impulse. The propellant combinations chosen encompass most of the common oxidizers and several of the families of rocket fuels. The three marginal indicators identify liquid-propellant systems already reduced to standard rocket practice in the United States. For comparison, the specific impulse values are listed at chamber pressures of 500 psia and 1,000 psia. (The increase in specific impulse with the increase in chamber pressure is primarily a function of the thermodynamic efficiency of the expansion processes. In addition, the higher chamber pressures suppress the dissociation of some of the exhaust products, resulting in higher kinetic temperature.) The propellant combinations involving nitric acid have a general order of 240 sec. of specific impulse. Specific impulse from combinations involving liquid oxygen show levels higher (15 sec. or about 6 per cent) than that for nitric acid and peroxide—namely, about 265 sec. Propellant combinations which utilize liquid fluorine as the oxidizer are theoretically capable of the highest specific impulse level, on the order of 325 sec. or a general increase of 20 per cent over the oxygen series. In addition to their specific impulse,

| ROCKET OXIDIZER | ROCKET FUEL | $I_{sp}$ at 1000 PSIA | $I_{sp}$ at 500 PSIA | at 500 PSIA $T_c$ (°F) | M | k |
|---|---|---|---|---|---|---|
| HYDROGEN PEROXIDE | GASOLINE | 273 | 248 | 4830 | 21 | 1.20 |
| HYDROGEN PEROXIDE | HYDRAZINE | 288 | 262 | 4690 | 19 | 1.22 |
| ► NITRIC ACID | GASOLINE | 255 | 240 | 5150 | 25 | 1.23 |
| NITRIC ACID | ANILINE | 258 | 235 | 5100 | | |
| NITRIC ACID | AMMONIA | 261 | 237 | 4220 | 21 | 1.24 |
| ► OXYGEN | ALCOHOL | 285 | 259 | 5560 | 22 | 1.22 |
| ► OXYGEN | GASOLINE | 290 | 264 | 5770 | 22 | 1.24 |
| OXYGEN | HYDRAZINE | 308 | 280 | 5370 | 18 | 1.25 |
| OXYGEN | HYDROGEN | 400 | 364 | 4500 | 9.0 | 1.26 |
| FLUORINE | AMMONIA | 337 | 306 | 7224 | 19 | 1.33 |
| FLUORINE | HYDRAZINE | 348 | 316 | 7940 | 19 | 1.33 |
| FLUORINE | HYDROGEN | 410 | 373 | 5100 | 8.9 | 1.33 |

FIG. 3. Specific impulse values.

| REACTANTS | |
|---|---|
| HYDROGEN | 1.00 |
| HELIUM | 4.00 |
| | |
| LITHIUM | 6.94 |
| BERYLLIUM | 9.01 |
| BORON | 10.82 |
| CARBON | 12.01 |
| NITROGEN | 14.01 |
| OXYGEN | 16.00 |
| FLUORINE | 19.00 |
| NEON | 20.18 |
| | |
| SODIUM | 23.00 |
| MAGNESIUM | 24.32 |
| ALUMINUM | 26.97 |
| SILICON | 28.06 |
| PHOSPHOROUS | 30.98 |
| SULFUR | 32.07 |
| CHLORINE | 35.45 |
| | |
| | |

| COMBUSTION PRODUCTS | |
|---|---|
| H | 1.00 |
| $H_2$ | 2.02 |
| C | 12.01 |
| N | 14.01 |
| O | 16.00 |
| OH | 17.01 |
| $H_2O$ | 18.02 |
| F | 19.00 |
| HF | 20.01 |
| CO | 28.01 |
| $N_2$ | 28.02 |
| NO | 30.01 |
| CF | 31.01 |
| $O_2$ | 32.00 |
| $F_2$ | 38.00 |
| $CO_2$ | 44.01 |
| $CF_2$ | 50.01 |
| $C_2F_2$ | 62.02 |
| $COF_2$ | 66.01 |
| $CF_3$ | 69.01 |
| $CF_4$ | 88.01 |

FIG. 4. Molecular weight.

the key parameters of combustion temperature ($T_c$), the molecular weight of the reactant products ($M$), and the value of $k$ are shown at 500-psia chamber pressure. Values of molecular weight for the combustion products formed from these twelve typical, across-the-board propellant combinations range from approximately 25 in the case of nitric acid and gasoline to a low of 8.9 in the case of fluorein and hydrogen. Combustion temperatures range from 7,940°F. in the case of fluorine and hydrogen to 4,220°F. in the case of nitric acid and ammonia. Values of $k$ range from a low of 1.20 to a high of 1.33. Are these the highest values of $T_c$ and the lowest of $M$ which can be obtained? We will examine these concepts in sequence to evaluate the possibility of improvement and limiting factors of each.

First, the molecular weight of exhaust products is not independent of the other terms in the impulse equation but is a result of interrelated thermochemical considerations involving temperature and pressure. For purposes of discussion, however, consider $M$ a distinctly independent term contributing directly to specific impulse. The question is: How low a molecular weight of reactant products is it possible to achieve from molecular systems? The table on the left-hand side of Fig. 4 lists all of the elements in the first three periods of the periodic table—hydrogen through chlorine. The atomic weights of these reactant atomic species range from 1 for hydrogen to 35 for chlorine. Inasmuch as the reacting chemical systems in rocket chambers being dealt with here do not change their atomic structure or atomic weight in moving from association in the reactants to association in the combustion products, it would appear that the absolute minimum molecular weight of combustion products formed (if the combustion products were by some untoward engineering feat pure hydrogen atoms) would have a molecular weight of $1^1/_2$ to 2. This value is the lowest possible value of $M$ which could ever appear in the specific impulse equation involving a molecular or atomic species. However, because chemical reactions between different atomic species are involved in rocket combustion, atomic and molecular species other than hydrogen will necessarily appear in the exhaust products. With this in mind, observe the table on the right of the figure. Listed are 21 of the more typical combustion products formed in rocket-combustion cycles. Molecular weights for these species range from a high of 88 for $CF_4$ to a low of 1 for the hydrogen atom. The exhaust gases from three typical propellant combinations, alcohol-oxygen, gasoline-oxygen, and ammonia-fluorine have an average molecular weight range of approximately 18 to 22. If our goal is the reduction of molecular weight to obtain high specific impulse, we must recognize, first that the average molecular weights in most rocket-propellant combinations are approximately the same, 20; and secondly, to achieve a reduction in these average molecular weights, we must both reduce the concentration of the high molecular weight species and increase the concentration of the lows. Fig. 4 also suggests that the use of fuel or oxidizer compounds consisting in whole or in part of third-period atoms, sodium, magnesium, aluminum, silicon, phosphorus, sulfur, and chlorine, with their relatively high atomic or molecular weights, 23 through 35, should be approached deliberately with the consideration that the employment of these heavier species will increase the average molecular weight of the exhaust products and may well decrease the specific impulse of the propellant combinations unless we can compensate with a very high $T_c$ or a higher percentage of hydrogen in the exhaust. From the molecular weight viewpoint, it can also be seen that the second-period light metals, lithium, beryllium, and boron, permit these atoms to be considered as possible constituents in rocket-engine combustion. The species hydrogen, carbon, nitrogen, oxygen, and fluorine have long been, and probably will be for some years to come, the basic atomic species participating in rocket combustion and expansion cycle theoretical considerations. It is here then, with the molecular weight, that the first barrier to infinitely high values of specific impulse derived from molecular power cycles is encountered.

Setting aside the question of molecular weights, now having established an absolute minimum value of 1 and attainable values of 8 to 10, and having also established the fact that values of 20 are today's $M$, let us consider the quantity, $T_c$, in the specific-impulse equation. This temperature, the kinetic temperature, is a measure of the translational energy within the gases which is available as work during the isentropic expansion in the rocket nozzle. $T_c$ is derived wholly from the translational energy imparted to the molecular species in the combustion products as a result of the fuel-oxidizer reaction in the combustion chamber. All energy generated in a rocket-combustion reaction is derived from the breaking of the chemical valence bonds and forces—constituting the energy of formation—in the fuel and the oxidizer molecules and the forming of new and usually stronger valence bonds in the gaseous reaction product molecules. Fig. 5 shows comparative values of chemical bond energies. The left-hand table lists several typical

chemical bonds which are present in today's fuels and oxidizers. The bonds linking carbon to hydrogen and carbon to carbon are bonds which build up the molecular lattice of jet fuel constituents. The bonds linking nitrogen to hydrogen are the structural elements of the hydrazine family. The bond of fluorine to fluorine exists in the oxidizer, fluorine. In general these fuel and oxidizer bonds are weak. Generally, from the point of view of ultimate energy from the rocket reaction, the weaker these reactant bonds are, the more energetic will be the reaction when they break. The right hand shows bond energies for several reaction products. In this case the association between the atoms is stronger and bond energies are high, the carbon to oxygen and the nitrogen to nitrogen bond having values of 256 and 225 kcal. In general the bond energies in the combustion products are stronger than the bond energies in the reactants. In selecting propellant combinations which will deliver high combustion temperatures, the choice of fuel and oxidizers will be centered upon compounds formed from low-strength chemical bonds which will, upon combination, lead to products which have high bond energies.

| REACTANTS | | COMBUSTION PRODUCTS | |
|---|---|---|---|
| C-O | 224 (KCAL) | C=O | 256 |
| C-C | 137 | N≡N | 225 |
| C-N | 129 | N=O | 150 |
| O-O | 117 | H-F | 134 |
| H-H | 103 | C-F | 106 |
| N-H | 85 | H-O | 103 |
| C-H | 80 | | |
| F-F | 36 | | |

FIG. 5. Valence bond energies.

There is another point to be considered in this figure. If the products of the reaction are heated to moderately high temperatures, the combustion product molecules are unable to absorb or to utilize this energy by translational activity alone. At specific energy levels or at points on the temperature scale (different for each compound and differing also by the rate at which the energy is absorbed) vibrational and rotational activity —in addition to the translational—of the species ensues, and at higher temperature levels products begin to absorb substantial quantities of energy first by dissociating, and eventually by ionizing. The only energy form of mode of the combustion products which is available for work in the exhaust nozzle is the translational mode. The vibrational, rotational dissociation, and ionization energies and certain higher forms involving electron activity in the molecule, are not available thermodynamically in the isentropic expansion of the gases in the nozzles. Measured flame temperatures in the combustion chamber are measurements only of this translational form of energy. This point will be considered in more detail later in this discussion.

The twelve propellant combinations listed in Fig. 3 will now be considered in respect to the combustion or flame temperatures which are theoretically produced by their reaction in a rocket combustion chamber at 500 psia. The highest listed combustion temperature is with the propellant combination fluorine and hydrazine, at a temperature of 7,940°F. The lowest flame temperature is with the propellant combination nitric acid and ammonia, calculated at 4,220°F. The others, ranging between these extremes, are oxygen and hydrogen at 4,500°F., hydrogen peroxide and hydrazine at 4,690°F., hydrogen peroxide and gasoline at 4,830°F., nitric acid and aniline at 5,100°F., fluorine and hydrogen at 5,100°F., nitric acid and gasoline at 5,150°F., oxygen and hydrazine at 5,370°F., oxygen and alcohol at 5,560°F., oxygen and gasoline at 5,770°F., and fluorine and ammonia at 7,224°F. The higher order combustion temperatures are a result of the breaking of weak F-F bonds and the forming of stronger H-F and N-N bonds. The lower order flame temperatures are low primarily because of lower order bond energy, although in some cases, the low temperatures are a result of advanced dissociation of some of the reactant products, particularly $H_2O$ and $CO_2$. For example, the low temperature of the alcohol-oxygen combination, 5,560°F., is in part a result of the fact that nearly 50 per cent of the combustion gases are composed of $H_2O$ or of $H_2O$ constituents.

Water begins to dissociate quite low in the temperature scale, 5 per cent being dissociated at 5,000°F. A part of the energy of the reaction is therefore lost as realizable nozzle work by the energy-wise dissociation of $H_2O$ and other species. Rocket-engine flame temperature, $T_c$, is therefore limited by the dissociation of the reaction products. Because almost all of the available reaction products in present-day rocket engines begin dissociating about 5,000°F. and reach advanced dissociation levels at 8,000° to 10,000° F., there is little possibility of the flame or kinetic temperature rising above values of approximately 10,000°F. Therefore another limit to specific impulse is present, molecular thermal dissociation.

Previous discussion has shown that there will be a practical limit in molecular weight of approximately 10. It is apparent that there is a practical limit in combustion temperature of approximately 7,000°F. This is not to say that higher flame temperatures are not available from chemical reactions. In fact, flame temperatures of 10,000°F. are possible from chemical reactions, but the fact that such a high value of $T_c$ is possible does not make it automatically an excellent rocket-engine propellant combination because the molecular weight of the particular gases which react at these high temperatures is approximately 28, appreciably higher than the molecular weight (18 to 22) listed for the more common propellant combinations. High chemical flame temperatures do not necessarily mean high specific impulses. High temperatures and low molecular weights are corequirements for high specific impulse.

The specific impulse equation also includes the $k$,

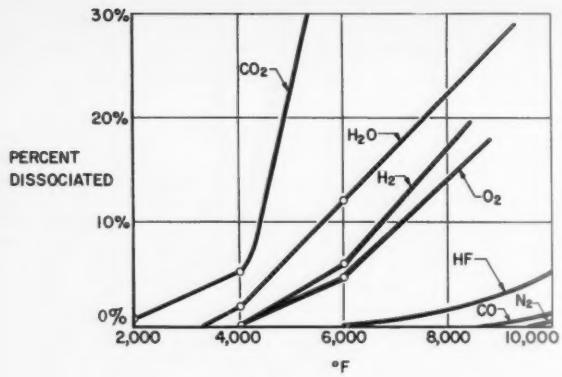


FIG. 6. Dissociation at 500 psia.

or gamma term. In general, low values of gamma mean high values of specific impulse, although the effect of gamma on specific impulse is minor. Gamma values for the reaction products of our twelve rocket propellant combinations range between 1.20 and 1.33 with the hydrogen peroxide oxidized combinations having the lowest value. Gamma values increase with nitric acid, oxygen, and fluorine oxidizers in that order.

The concept of gamma, the ratio of the specific heat at constant pressure $c_p$ to the specific heat at constant volume $c_v$, cannot be rigorously applied when determining specific impulse. This is primarily because as the reactant products expand in the nozzle, some reassociation takes place and a variety of gamma values, difficult to handle mathematically, are established. The concept of an exact gamma is clouded by dissociation and recombination to such an extent that one more correctly speaks of *apparent* gamma values. In truth, present-day concepts in rocket engine propellant calculations are doing away with the concept of gamma altogether. Values are noted here primarily because gamma does fit in the theoretical specific impulse calculation and a presentation of this sort would not be complete without mention of it.

Returning for a moment to flame temperature, Fig. 6 shows graphically the extent of the dissociation of the exhaust products plotted against temperature. Species plotted are CO, $CO_2$, $H_2O$, $H_2$, HF, $N_2$, and $O_2$, some of which are ordinarily found in most rocket engine exhaust gases. As these species are heated to higher kinetic temperatures, the per cent of dissociation increases. The figure shows that the species of CO and $N_2$ are remarkably stable, while the species $H_2O$ and $CO_2$ are the least stable.

By incorporating the best qualities of $T_c$, $M$, and $k$ from the preceding figures we can predict, theoretically, rocket propellant performance. The highest temperature system known to be feasible from ordinary molecular reaction involves cyanogen ($C_2N_2$) and ozone ($O_3$) with a combustion temperature of 9,467°F. Although this is a molecular system of extremely high temperature (because of its stable NN and CO products), it is not the highest specific impulse system from a rocket viewpoint. The lowest molecular weight system which seems reasonable is one of hydrogen and fluorine, with a molecular weight in the exhaust gases of 8.9. Specific impulse for this system is 373 sec. This $M$ value of 8.9 is determined by the point at which the $I_{sp}$ value is maximum. The reaction can be run at very hydrogen-rich conditions, putting increasing amounts of unreacted $H_2$ and H in the exhaust gas, lowering the average molecular weight below 8.9. However, the flame temperature of this more fuel-rich mixture (even at 8.9 the reaction is well on the fuel-rich side of stoichiometric) is low and $I_{sp}$ falls. Moving to a stoichiometric equation gives a maximum temperature accompanied by a high molecular weight.

The lowest gamma system has a value of 1.2 and involves the constituents hydrogen peroxide and gasoline. The value of $c_p/c_v$, near unity in this instance, results primarily from the higher percentage of relatively complex molecules in the exhaust arising from lower temperatures and the gasoline fuel. The specific impulse of this low gamma system is 248 sec.

Gathering values of $T_c$, $M$, and $k$ and applying mutually compatible maximum values of these, we find that the highest rocket performance system for chemical reaction is apparently the system of fluorine and hydrogen with a specific impulse of 373, closely followed by the oxygen-hydrogen system at 364.

Here, then, for all practical purposes is the limit of performance from the reaction of chemical constituents in rocket combustion chambers. The barriers (if you will) preventing the attainment of performance higher than this from chemical reaction are three: the bond energy barrier, the molecular weight barrier, and the molecular dissociation barrier.

Question No. 4 in the introduction to this paper asked what the obstacles to developing and applying these higher-energy rocket-propellant systems (those systems which lie above gasoline-oxygen, 264 sec., on the $I_{sp}$ scale) will be. There are six problems which, I think, confront the rocket propellant chemist and power-plant engineer in procuring higher specific impulse values. These problems are: (1) high reactivity of compounds, (2) high instability of the compounds, (3) catalytic instability, (4) personal hazard, (5) difficult low temperature properties, (6) high vapor pressures, and (7) higher cost. All these chemical problems are fundamentally a result of striving to obtain higher gas temperature and lower molecular weights. Pushing rocket fuels and rocket oxidizers toward weaker bond energies results in more reactive compounds, more unstable compounds and, generally, more toxic compounds. Hydrazine ($N_2H_4$), for example, is a higher-energy fuel, but it is more unstable, more reactive, and more toxic than gasoline. The desirability that fuels contain a large percentage of hydrogen (molecular weight = 2) implies that such fuels will generally tend to become more and more gaseous to the point where, at the chemical ultimate, the fuel is 100 per cent hydrogen, the normal boiling point of which is −423°F. Developing more energetic fuels and oxidizers—or

(*Continued on page 68*)

*Guidance without the use of any radiation; describable by the laws of mechanics and involving measurements of time, gravitation, acceleration, and angular velocity.*

# Inertial Guidance

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## Introduction

INERTIAL GUIDANCE is defined as guidance without the use of any radiation, either natural or man-made. It is a process describable by the laws of mechanics, and as such it involves the measurements of time, gravitation, acceleration, and angular velocity. Self-contained measurements of these quantities are necessarily obtained with respect to inertial space, rather than relative to the Earth; hence the term inertial guidance. (Inertial space is the basic reference frame for Newton's laws of mechanics; it is generally associated with the "fixed stars.")

The uniqueness of the vertical—i.e., the direction of gravity—at any point on the Earth is the basis for astronomical position.[1] This direction is compared with Earth-reference directions to obtain the necessary guidance information. To examine the nature of this comparison, consider that, in the first place, all inertial position data are in the form of nearly geocentric angles. For example we may take *astronomical latitude*, the complement of the angle between a line parallel to the Earth's polar axis and the local gravity vector. (The undulations of the geoid, or Earth-figure, may make it necessary to translate the polar axis parallel to itself, in effect, in order to have it intersect the local vertical.)

And we can also take *astronomical longitude*, the angle about the Earth's polar axis between a reference vertical (usually that at Greenwich) and the local vertical. Because of the arbitrary choice of reference vertical, longitude is not inertially unique, although change of longitude is. Other forms of position reference may be used—e.g., along and across a great circle that represents a desired path of travel.

**This is a condensation by the authors of the paper of the same title which was presented at the Self-Contained Air Navigation Systems Session, IAS 25th Annual Meeting, N.Y., Jan. 28–31, 1957. A revision of the paper is available as Fairchild Fund Paper No. FF-16.**

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## Angle Indication

It would be most desirable to obtain the position reference data directly relative to the Earth. Actually, such information can only be obtained relative to inertial space by self-contained measurements—i.e., not involving external radiation—and must then be converted to Earth-referred data. Accordingly, all inertial guidance systems contain the following four devices:

(1) A mass-force measuring device, which is composed of accelerometers or pendulums and attendant gear, to indicate the vertical; this is the accelerometer package (Fig. 1a).

(2) An inertial space reference device, which is composed of gyroscopes and attendant gear; this is the gyro package (Fig. 1b).

(3) An azimuth measuring device to ensure proper orientation of the accelerometer reference axes (in certain systems, this may be included under (2) above).

(4) Indicating equipment to display the navigation data.

The method by which parts (1) and (2) above are interrelated leads to three basic configurations for inertial guidance systems.

The three basic inertial guidance configurations are as follows: (a) The accelerometer package is mounted so that the indicated vertical coincides with one axis of the gyro package (see Fig. 2), giving analytic reference storage. (b) The accelerometer package indicates the vertical, but the gyro package indicates inertial space, in which case one axis of this package may indicate the Earth's polar axis (see Fig. 3), giving geometric reference storage. (c) A three-unit accelerometer package is fixed relative to the gyro package, which indicates inertial space (see Fig. 4), giving analytic storage of all directions.

These three basic configurations represent different methods of comparing the coordinate frames essential to navigation. The accelerometer and gyro packages represent the instrumentation of certain of these frames.

In Fig. 2 the combined accelerometer-gyro package instruments the astronomic frame; no other frames are directly instrumented. Guidance data are obtained as

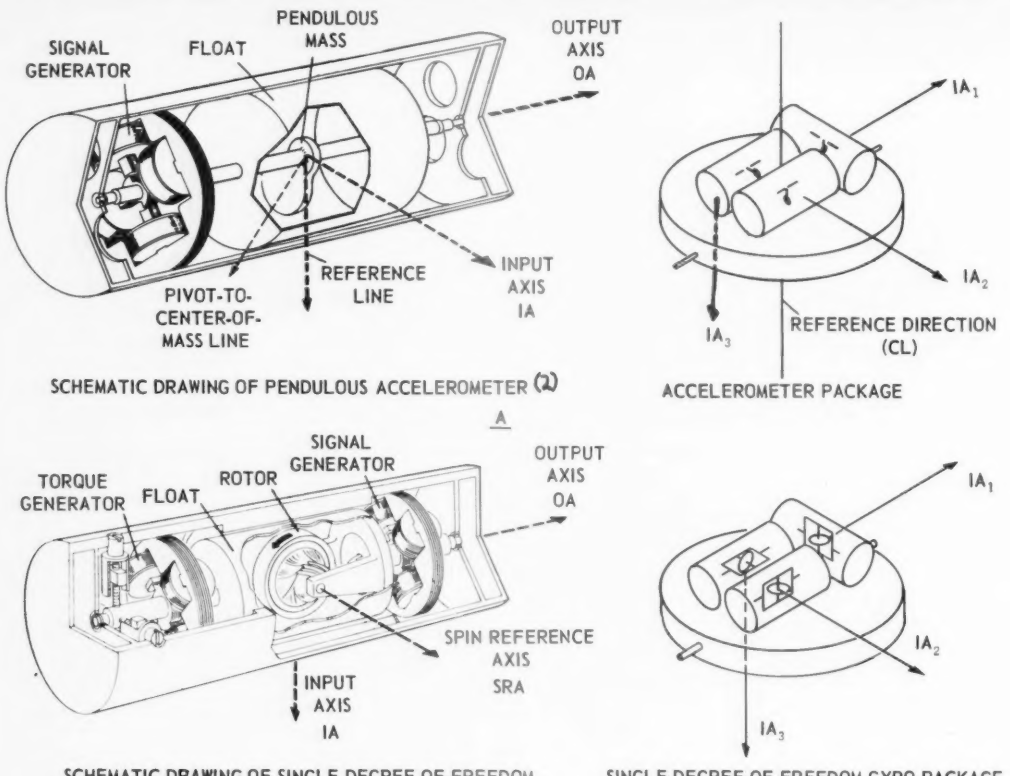


FIG. 1. Accelerometer and gyro packages.

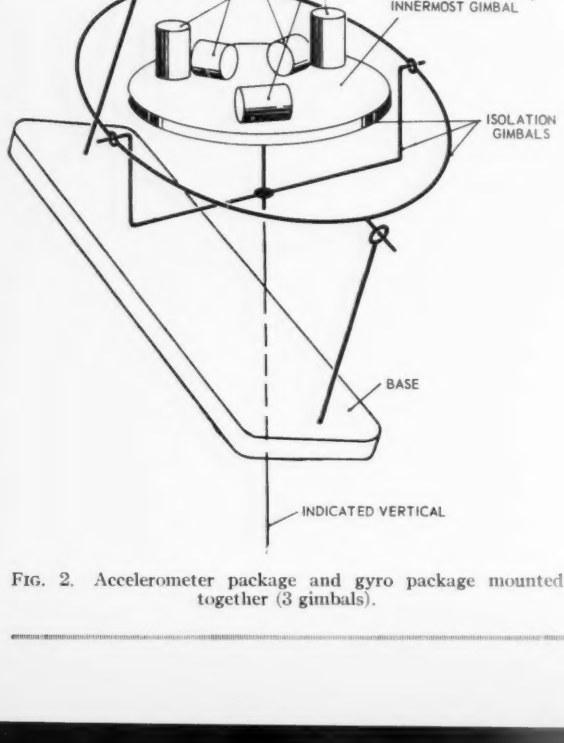


FIG. 2. Accelerometer package and gyro package mounted together (3 gimbals).

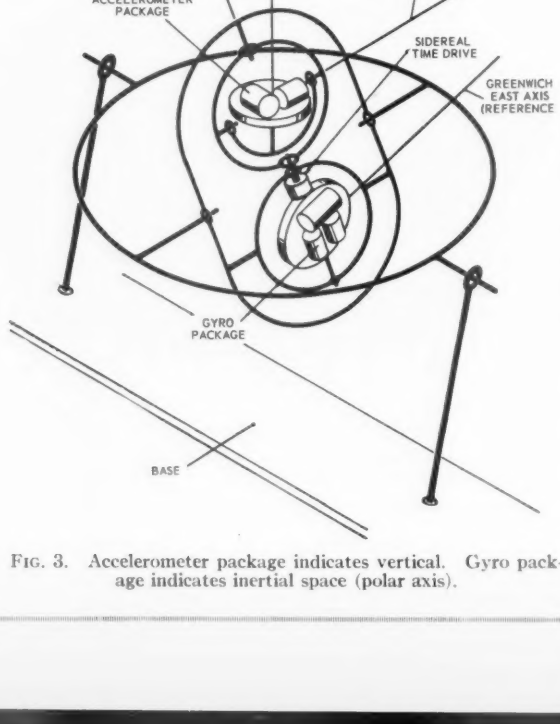


FIG. 3. Accelerometer package indicates vertical. Gyro package indicates inertial space (polar axis).

signals representing velocity or acceleration measurements relative to the geocentric inertial frame and converted into Earth data via signal operations. Thus the astronomic frame is related to the Earth reference frame, and in the process, the necessary guidance information is obtained by means of the integration of data in the form of signals.

In Fig. 3 the accelerometer package instruments the astronomic frame and the gyro package instruments the inertial frame. The Earth reference frame is related to the inertial frame geometrically. Guidance data are then obtained by direct angular measurements between the astronomic frame and the Earth reference frame.

In Fig. 4 the combined accelerometer-gyro package instruments the inertial frame. Guidance data are then obtained entirely by means of signal processing.

### Geocentric Rotation

The early "artificial horizon" technique for indicating the vertical implied a "flat Earth" model, for measurement purposes. That is, gravity was assumed to be constant in direction, while accelerations were considered to be either varying in direction or limited in time duration. Thus an indicator of the vertical became a low-pass filter. The difficulty in constructing a mechanical filter with a time parameter of several minutes led to devices of an accuracy of about one-half degree or more during vehicle maneuvers; this is only moderate accuracy by present-day standards.

Any more precise treatment of the indication of the vertical from moving bases should use the concept of a geocentrically rotating vertical.

### Fundamentals of the Schuler (84-Minute) Pendulum

Schuler[1] pointed out in 1923 that on a spherical Earth accurate indication of the vertical during period of acceleration could be realized by suitable tuning of the natural period of a pendulum. Whenever the pivot of a pendulum is accelerated, the center of mass of the pendulum tends to "lag behind" the pivot with respect to inertial space. At the same time, this acceleration causes the true vertical, which is a line through the center of the Earth and the pivot under the simplifying assumptions used in this treatment, to accelerate geocentrically with respect to inertial space. The rotational sense of these two motions is the same. These considerations lead to the following observation: If a pendulum initially hangs vertically, it will remain along the vertical if, as seen from inertial space, *its angular acceleration about its pivot equals the geocentric angular acceleration of the vertical.*

When operation is in the Earth's gravity field and the pendulum is undamped, this condition gives a pendulum with a natural period of approximately 84 min.; hence the term "84-minute pendulum." For a shorter-period pendulum, the rotation-producing torque on the pendulous element about its pivot is stronger, so the pendulum rotates too rapidly and lags the true vertical. For a longer-period pendulum the torque is weaker and the pendulum leads the true vertical.

An 84-min. period is very long compared to the periods of physical pendulums ordinarily encountered. A condition analogous to the Schuler tuning of a pendulum can be realized in a particular kind of closed-loop system in which a short-period pendulum or accelerometer tracks the specific force. A platform driven by a space integrator and controlled by signals derived from the pendulum output data then becomes an "equivalent Schuler pendulum."

### Closed-Loop Equivalent Pendulums—Gravity Tracking

The equivalent pendulum can be considered to be composed of: (1) A force-measuring subsystem which may involve either pendulums or accelerometers and which has the function of measuring the total mass force direction or component magnitudes. (2) A torque-producing subsystem which is a space integrator—either a gyro package which is precessed and which supports the force-measuring subsystem directly or a set of integrating drive motors which operate between an inertial gyro package and the force-measuring subsystem. (3) A dynamic control subsystem where, in the case of a linear system (the only type treated here), the parameters controlled may be expressed as damping ratios, natural frequencies, and characteristic times.

The coupling between the essentially nondynamic force-measuring subsystem and the space integrator can take many forms. The following are of particular

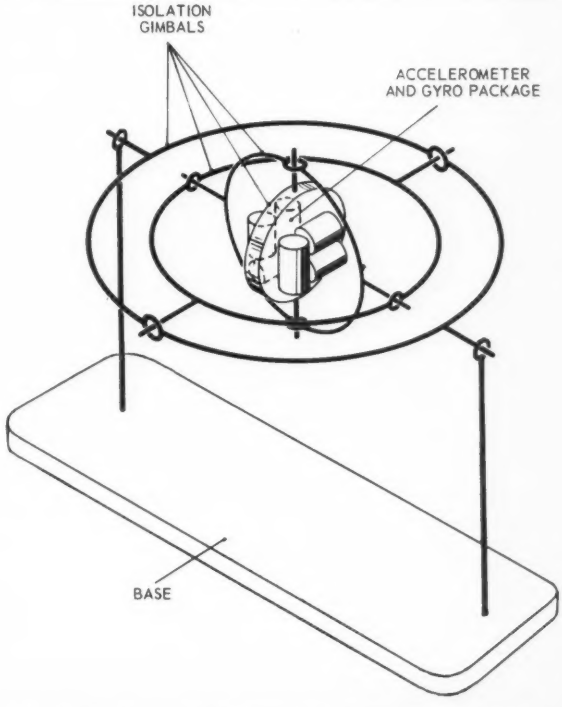


Fig. 4. Accelerometer package fixed to gyro package, which is inertial.

interest, in the ideal case: A nondynamic coupler between the force-measuring subsystem and the torque-producing subsystem; an integrator; an integrator and by-pass, which act as integration coupled with lead (relative to the integrator output); and an integrator and by-pass followed by a lag or a low-pass filter.

These monitoring-components choices result in, respectively (1) A system describable by a first-order differential equation with the angle measured from indicated to true verticals, the correction to the indicated vertical as dependent variable, and time as the independent variable. One integration process, provided by the space integrator, is present in the loop. This system behaves like a pendulum that is heavily overdamped with respect to inertial space.

(2) A second-order undamped system, which behaves like an undamped pendulum.

(3) A second-order damped system, which behaves like a pendulum damped with respect to inertial space.

(4) A third-order damped system, which behaves like a pendulum damped to inertial space by so-called "differentiated tachometer feedback" type of damping, although no tachometers or differentiators as such are actually present.

The criteria for selecting any one of these methods rather than the others are such considerations as the component complexity permitted in the design, the amount of smoothing, and the requirement for damping. The overriding consideration, however, may well be the effect of forced errors.

## Inertial Control of a Vehicle

Any course over the surface of the Earth may be defined for inertial guidance by a continuous series of local verticals that pass through the course. The discussion in this section will be limited to the astronomic great-circle case.

The desired control of a vehicle may take one of two forms. The first of these is the control of the vehicle in order to traverse the desired course. This is the track-control problem. It reduces to the problem of making the local vertical through the vehicle lie on the surface defined by the verticals along the programed course. In some instances it is required that the vehicle travel along the course at a predetermined rate, such that the vehicle will have a position at any time which corresponds to a predetermined velocity program. This is the range-control problem and involves making the local vertical through the vehicle coincident with a particular vertical along the programed course at any given time.

If track control alone is required, this can be accomplished by controlling only the direction of the velocity vector with respect to the supporting medium. If both track and range control are desired, both the direction and magnitude of this velocity vector must be controlled. Control of the magnitude of the velocity vector involves continuously variable control of the vehicle's power plant, which in most cases is undesirable, particularly in the case of aircraft in the presence of fluctuating winds, and almost impossible with some types of power plants.

Ideal control in track would be achieved if the velocity of the vehicle with respect to the supporting medium were made equal to the difference between the desired velocity of the vehicle with respect to the Earth and the velocity of the medium with respect to the Earth. In other words, for air-borne track control operations, the component of air speed across the track should be equal to the negative of the component of wind across the track. This is accomplishable inertially by controlling the velocity of the vehicle with respect to the supporting medium as some function of the difference in direction between the apparent and the programed verticals.

The Schuler tuning is inherent in any inertial control system since the control represents geocentric rotation of the vehicle at Earth-radius distance in the gravity field.

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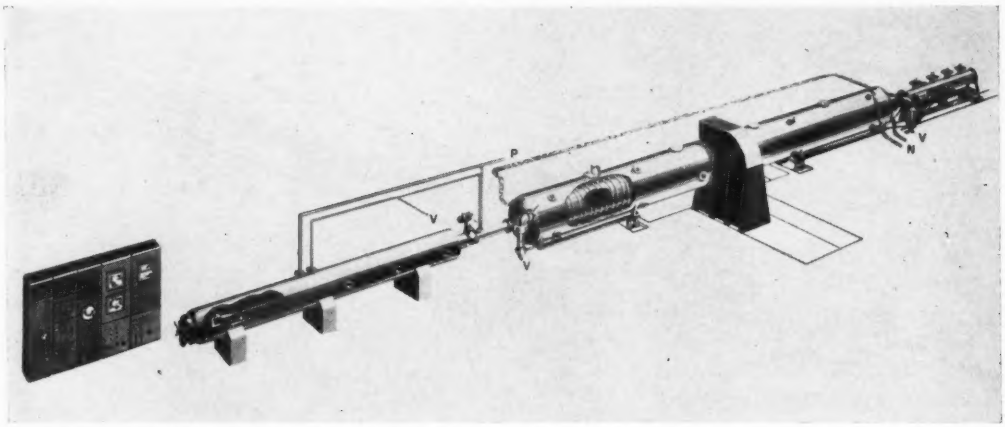

FIG. 1. Artist's conception of the Controlled-Temperature-Pressure Range and its associated controls.

# The Controlled-Temperature-Pressure Range

*A survey is given of the research and development program which has culminated in operation of the Controlled-Temperature-Pressure Range (CTPR) for production of flows up to Mach 11. Methods of control of temperature and pressure in the 45-ft. working section are described. The instrumentation necessary for measurement of (1) projectile drag coefficient and (2) density throughout the field of flow is discussed.*

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## INTRODUCTION

### *Historical Survey*

THE DEVELOPMENT PROGRAM which has culminated in the high Mach Number instrument called the Controlled-Temperature-Pressure Range, abbreviated CTPR, had its first beginnings in the period from 1944–1946. During this interval Col. Paul Libessart, of the French Army, and Drs. R. F. Clippinger, I. E. Segal, and R. N. Thomas in various conferences and memoranda evolved the idea of an enclosed firing range in which the working fluid could be maintained at closely controlled pressure and temperature. While the earliest record is in the form of a typewritten memo dated June, 1944, from Colonel Libessart to the late Dr. Edwin P. Hubble who was then director of the Exterior Ballistics Laboratory, the final design is the conception of its principal architect, Dr. R. F. Clippinger. Subsequently many people have participated in the construction, modification, and operation of the CTP Range. Some of their contributions appear as items in the reference section of this paper and will be indicated by number in the text.

From the beginning it was clearly recognized that control of temperature, particularly through use of refrigerants such as liquefied gases, offered the possibility of choosing the ambient velocity of sound so as to obtain high Mach Number flows about freely moving supersonic projectiles. Through use of refined optical techniques offered by the Mach-Zehnder interferometer it was hoped that comparisons could be drawn between experimentally produced and theoretically calculated fields of flow.

The seemingly easier objective of high Mach Numbers has been realized only recently while the apparently more complex comparisons of experimental and calculated flows[1, 2] could be carried out earlier. Certain simple cases were studied in a prototype Model Range with pressure control only. This prototype, which is now in its Mark II design, was constructed expressly to provide experience with an enclosed, pressurized range. Many valuable results have been obtained from it, and lessons have been learned which could be applied to problems of instrumentation for the CTPR. The Model Range remains a useful tool for studies requiring variable density only but has been superseded by the CTPR where high Mach Numbers are desired.

**This is a shortened version of a paper presented during the Aerodynamics Range Symposium on Jan. 24–25, 1957, at the Aberdeen Proving Ground. For the full text see *Proceedings of the Aerodynamics Range Symposium*, BRL Report 1005, Part I (Unclassified), pp. 151–182, March, 1957.**

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FIG. 2. Enlarged view of central working section seen in Fig. 1.

## RANGE DEVELOPMENT

### *Control of Pressure and Temperature*

In Fig. 1 is given an artist's conception of the CTPR in schematized form. The main outlines of the three principal parts—viz., the gun chamber, central working section, and stopping section—can be seen. The oil-diffusion vacuum pumps and the pressure and nitrogen lines are indicated by V, P, and N respectively. Fig. 2 shows an enlarged view of the working section and stopping tube. The dark frame in the center represents the external housing of the 10-in. Mach-Zehnder interferometer. At the cutaway section may be discerned both the annular evacuated space between inner and outer cylinders and the cooling and heating coils wrapped around the inner chamber.

Both the type and density of the working fluid can be controlled in the CTPR; thus $\gamma$ and $\rho_1$ may be chosen as desired throughout the gamut of available gases and continuously in the domain of pressures $0 \leq p \leq 10$ atm. For most room-temperature experiments dry air, dew point $t_s \leq -70°$F., from the wind-tunnel sphere is used both as working fluid and as a rinse for the gun section after firings. Since the combined volumes of the CTPR sections do not exceed 600 cu.ft. and ordinarily only about one third of this volume is changed per firing, the demands on the sphere supply are not high. At the extreme low temperature $T \doteq 80°$K., only permanent gases may be used. The choice so far has been dry nitrogen mainly because of its similarity to air and secondarily because it can be conveniently introduced from the piping system carrying the refrigerant.

Control of temperature is achieved by circulating liquids or gases in two sets of cooling coils, with top and bottom headers, placed as uniformly as possible around the 45-ft., stainless-steel, inner cylinder of the working section.

For low-temperature runs, liquid nitrogen supplied by tank truck and centrifugally pumped through one set of coils at pressures up to 30 psi provides a minimum temperature near 85°K. over the entire observation chamber. Heat gains from the outside shell are minimized by maintaining the intervening annular space at high vacuum, $p \leq 0.05$ micron, and insulating the inner evacuated wall with several layers of aluminum-foil radiation shield.

Temperatures higher than ambient are obtained by circulating electrically heated oil from an insulated tank through the other set of coils. The upper temperature limit $T = 400°$K. is set by the efficiency of the oil heating system and the chemical stability of the oil.

### *Instrumentation*

The working section of the CTPR has five sets of paired crossed windows with 6-in. diameter apertures separated by 9-ft. intervals. Each is instrumented for spark shadowgraph records except at the center station. Here a horizontal window pair for shadowgraph and triggering beam apparatus precedes by about 2 ft. a vertical station with 10-in. diameter, optical-glass windows accurately aligned for the 10-in. Mach-Zehnder interferometer.

Reference marks in the shadowgraph stations are surveyed to an accuracy of 0.001 ft. on the centerline, and the stations are rendered perpendicular to the centerline to within a few seconds of arc by means of a precision telescope and optical square.

Time of flight intervals between shadowgraph stations are measured to within $\pm 0.1$ microsec. by means of Hewlitt-Packard 10-mc. counters.

The 10-in. Mach-Zehnder interferometer, one of the largest of its kind used for full-field flow surveys, is equipped with an exploding-wire light source,[3] a liquid-prism monochromator,[4] and rotating-mirror camera. The instrument itself is arranged as shown in Fig. 3 with its 10-in. elements at the vertices of a 60°–120° parallelogram oriented perpendicular to the range centerline. Fringes parallel to the centerline fulfill both the condition for optimum light source[5] and the

requirements for precision measurement of fringe shift in the field of flow (reference 2, Sect. IV).

### *Projectile Launchers*

The absolute velocity attainable in a free flight range is set by the types of projectile launcher available. Until recently cal. .30 and cal. .50 smoothbore and rifled guns were the principal means of launching projectiles. Full-size spin-stabilized missiles with driving bands and subcaliber missiles with separating sabots have been extensively used for experimental firings. With cal. .30 fixed ammunition and special powder loads, velocities up to 5,000 ft. per sec. can be reliably obtained. With the cal. .50 smoothbore, velocities up to 6,000 ft. per sec. have been achieved in a number of programs.

Quite recently a cal. .75 smoothbore gun[6] with detachable chamber and detached ammunition has been used to fire subcaliber, nonspinning, statically stable rounds in separating sabots. Velocities up to 7,000 ft. per sec. at the muzzle have been attained.

### *Mach and Reynolds Number Bounds*

Since a principal feature of the CTPR is its potential to utilize cooled gases in which the velocity of sound is low, one expects the span of accessible Mach Numbers to be considerably enlarged. Assuming a perfect gas law dependence of sound velocity on absolute temperature, we find that, at the lowest temperature of the CTPR, Mach Number can be increased by a factor of approximately $(300/85)^{1/2} \doteq 1.9$. Thus with the cal. .75 projectile launcher, the highest Mach Number attainable is slightly less than 12. On the lower side, firings below $M = 1$ have been made on occasion, but routine studies much below $M = 1.2$ are complicated by interference from reflected shock waves. We may then say that, with its present instrumentation, the Mach Number scale of the CTPR satisfies the inequality $1.2 \leq M \leq 12$.

Since density may be controlled directly in the CTPR, it is possible to make Reynolds Number $Re$ vary over a considerable range of values. With standard values of the physical constants for the density, viscosity, and molecular weight of air, we can find for $Re = (\rho VL/\mu)$ the value $Re_s = 0.55 \times 10^6$ per in., per Mach Number per atmosphere at $T = 300°K$. Since, at constant pressure, density varies inversely with temperature, specific Reynolds Number $Re_s$ increases with decreasing temperature and at our low temperature limit would be larger by nearly four times.

To illustrate the possible span of Reynolds Number values, we note that, since the CTPR can be evacuated to pressures below 1 mm. Hg, the lower bound is zero and may be approached as closely as we like. For a representative projectile, say 0.5 in. in diameter, a room temperature study could be carried out at $M = 6$ over the full pressure range $0 \leq p \leq 10$ atm. and the corresponding Reynolds Numbers would be $0 \leq Re \leq \times 1.5\ 10^7$.

Since the boiling point of oxygen is 90°K., air cannot be used at the extreme low temperature. Nitrogen which boils about 77°K. has been used successfully at pressures less than 1 atm. Here the maximum $Re$ for our example would be smaller by a factor of about three.

At the maximum Mach Number and pressure, a room temperature study could be made at about $Re = 3 \times 10^7$, at least in principle. Actually at densities above that characteristic of air at room temperature—i.e., $\rho_1 = 1.2$ gm./$l$—a number of difficult problems of measurement appear which severely limit the accuracy possible. To cite a few of these:

(1) A high-velocity missile decelerates an appreciable fraction of its velocity in 50 ft. of travel when air densities in excess of $3\rho_1$ are used.

(2) Shadowgraph and interferometer records are complicated by very large refraction effects.

(3) Refraction may cause important portions of the optical record—i.e., large bundles of light rays—to miss the rotating mirror entirely and fail to show on the photographic plate.

(4) Stability of the projectile if spin stabilized may be adversely affected.

While the potentiality for specification of $Re$ through a considerable range of values is a feature of the CTPR, practical limitations—which can eventually be removed or minimized—have confined variable Reynolds Number studies so far to Mach Numbers less than 6 ($M \leq 6$) and densities less than 3.2 gm./$l$($\rho < 3\rho_1$).

It is clear that Reynolds Number cannot be controlled independently of Mach Number unless compensating

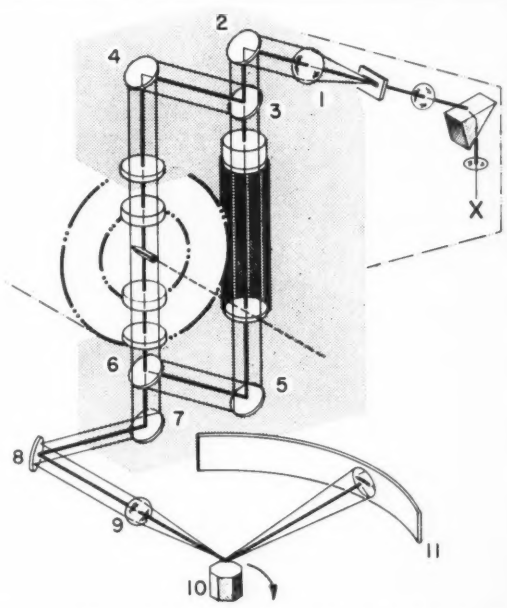


FIG. 3. Schematic diagram of the 10-in. Mach-Zehnder interferometer. Spark source and liquid-prism monochromator appear at the upper extreme right. One beam passes through the CTPR, the other through a cylindrical compensating chamber. Components may be identified as follows: $X$ = light source; 1 and 9 = lenses; 3 and 6 = divider plates; 2, 4, 5, 7, and 8 = plane mirrors; 10 = rotating mirror; 11 = film holder.

changes are made in one of the other variables such as density, projectile size, or type of gas. It is found experimentally that quantities such as drag coefficient $K_D$ depend only weakly on $Re$ over considerable ranges of $M$. Thus in presenting $K_D$ vs. $M$ data, the variation of $Re$ from point to point is frequently ignored.

## Some Recent Flow Investigations

### *$K_D$ and Wake Angle Measurements*

An account is given elsewhere[8] of application of the CTPR in the investigation of observable properties of the flows about proposed nose models for the ICBM program. The studies made so far represent attempts to simulate normal density flows for the Mach Number span $4 \leq M \leq 10$.

The demand of this program for data at higher Mach Numbers has greatly stimulated concomitant development of high-velocity missile launchers. This Laboratory has under procurement at the present time two guns of the type developed by Drs. Slawsky and Seigel of the Naval Ordnance Laboratory. When these have been obtained and proved, extension of the present Mach Number range by a factor of two is to be expected. This should make accessible to study flows with an appreciable degree of ionization. Whether the interferometric techniques discussed here can be used to explore the properties of a self-luminous, highly excited medium remains open to question.

### *$K_D$ vs. M for a Blunt Cone-Cylinder*

In any discussion of an instrument such as the CTPR, the question naturally arises as to how well flows produced by models at low temperatures and high Mach Numbers simulate those produced by models or full-scale objects at the same Mach Numbers and ordinary temperatures. To provide a partial answer to this complex question, studies of $K_D$ vs. $M$ for a blunt cone-cylinder—i.e., a 35° half-angle cone-cylinder—have been made at 300°, 105°, and 85°K. Before discussing some of these results a few remarks will be interpolated to clarify the situation.

If the equations governing the conservation of mass, momentum, and energy for a viscous, heat-conducting, compressible fluid be rendered dimensionless through the introduction of suitable transformations on the dependent and independent variables, then a set of partial differential equations emerges which not only is free of dimensions but also exhibits certain dimensionless functional coefficients which appear as multipliers of the various derivatives.

These coefficients are $\gamma = C_p/C_v$, $M = V/a$, $Fr = V^2/gL$, $Re_1 = \rho VL/\mu$, $Re_2 = \rho VL/\lambda$, and $W = k\theta/\mu V^2$. Here $\gamma$, $M$, and $Fr$ represent specific heat ratio, Mach Number, and Froude Number respectively; while $\mu$ and $\lambda$ stand for the first and second coefficients of viscosity and $Re_1$ and $Re_2$ the corresponding Reynolds Numbers. The quantity $W$, in which heat conductivity $k$ and a characteristic temperature difference $\theta$ occur, has no conventional name but is discussed by Dryden[18] and is recognizable as the ratio of heat flow to energy dissipated by viscous friction. Depending upon assumptions defining relative orders of magnitude of heat flow, viscous dissipation, and kinetic energy, other dimensionless quantities such as Nusselt Number or Prandtl Number may enter through the boundary conditions of a given problem.

If flows about two similar objects of different size, say two spheres in an infinite medium, are to have the same dimensionless solution to the flow equations, then the six coefficients just listed must be preserved without change in the two situations. In addition, initial conditions and conditions at the boundaries must be rendered in dimensionless form and dimensionless coefficients preserved.

In supersonic flow problems encountered in firing ranges it is customary to regard gravitational effects as negligible. Thus Froude Number may be disregarded. If heat flow were small compared to viscous dissipation, $W$ might be neglected. On the other hand, it has long been understood that conditions on the heat transfer at the flow boundaries determine whether $W$, Nusselt and/or Prandtl Numbers will be of importance. In some range experiments missiles are heated or cooled in order to control these modeling parameters. In experiments to date with the CTPR this has not been done. Comparisons among various drag data are made simply ignoring the fact that $W$, $Pr$, and $Nu$ have not been controlled in the modeling.

As for second coefficient of viscosity the view is taken that either the Stokes' relation $\lambda + 2/3\mu = 0$ holds or the effects of $\lambda$ can be ignored—or if not ignored are strictly proportional to those of $\mu$. Under any of these conditions $Re_2$ can be either ignored or lumped with $Re_1$. This leaves then three coefficients to preserve in the preliminary modeling experiments—viz., $\gamma$, $M$, and $Re_1$.

The first of these, $\gamma$, is usually regarded as constant. Tables of this ratio for air or nitrogen[9] show deviations from $\gamma = 1.40$ of slightly more than 1 per cent in the temperature range $100 \leq T \leq 300$°K. As the boiling point of air or nitrogen is approached the deviations become larger. The data for nitrogen at one normal density—i.e., approximately 1/3 atm—suggest that at $T = 85$°K. the 1 per cent limit may not be exceeded. For these reasons $\gamma$ is assumed to be the same constant in both the room and low-temperature experiments.

Mach Number is chosen to be the independent variable in both experiments. While clearly the room temperature tests cannot reach the high Mach Numbers accessible at low temperatures, a considerable overlap in the range of values $4 \leq M \leq 6$ is possible where $K_D$ values ought to be directly comparable. $Re_1 = \rho VL/\mu$ is the one remaining coefficient whose value must be preserved in the two experiments. Because velocity of sound variation with absolute temperature is the essential factor in attainment of the high Mach Number data, the dependence of $Re_1$ on $M$ is shown by writing $Re_1 = \rho LMa/\mu$ where $V = aM$.

If it were true that the temperature dependence of $a$

and $\mu$ were the same, then the problem would simplify to that of maintaining $\rho L$ = const. for a given Mach Number. Simple kinetic theory predicts that both $a$ and $\mu$ should be proportional to $T^{1/2}$. In the present study of the blunt cone-cylinder it is assumed that the temperature effects of $a$ and $\mu$ do cancel. For constant missile size $\rho$ is adjusted to have the same value at low temperature as at room temperature. This means working at something less than 1/3 atm when $T \doteq 85°$K. The further assumption is made that in the nonoverlapping region of $M$—i.e., for $M \leq 6$—the increased $Re_1$ has little effect on $K_D$ or other flow parameters being studied.

The assumption that the temperature effects of $a$ and $\mu$ cancel is not strictly valid. For velocity of sound in nitrogen or air, the relation $a = CT^{1/2}$ holds within about 3 per cent for temperatures $100 \leq T \leq 300°$K. at 1 atm pressure. Viscosity of air or nitrogen varies closely as $T$ raised to the 8/9 power for the same range of temperature. Thus the simplifying assumption is only a crude representation of the facts. For a fixed projectile size $L$ to render $Re_1$ = const. precisely, one would have to adjust density so that $\rho$ = const. $\times \mu/Ma$. The measurements of $K_D$ vs. $M$ made for comparison purposes at $T = 300°$ (105°) and 85°K. for the blunt cone-cylinder[7] show $K_D$ values at all temperatures falling quite well on a continuous curve. As $K_D$ is relatively insensitive to $Re_1$, minor variations in this quantity appear to have no significance even up to a fivefold variation in $Re_1$. This is in contradiction to preliminary measurements made before precise determinations of ambient density could be made.[10]

The relatively small failures indicated above to model $\gamma$ and $Re_1$ accurately are often completely masked by experimental difficulties indicative of the crude approach followed during these early uses of the CTPR. Until recently, temperature gradients in the range introduced uncertainty to the interpretation of thermocouple measurements and, as a consequence, into the calculation of the ambient density $\rho_1$. Some of the discrepancy between early groups of measurements can be traced to erroneous $\rho_1$ values used to calculate $K_D$. Improvements in temperature control and uniformity have brought better agreement between recent series of $K_D$ values.

Among other sources of error at room temperatures are the unaccounted for variations in $\gamma$ and molecular weight of the working fluid caused by contaminants from the burnt powder gases. In spite of multiple baffle systems, some contamination can hardly be avoided—and cannot at present be detected until a system of chemical analysis of the medium or precise measurement of its characteristic sound speed allows continuous monitoring of the composition of the medium. At the low temperatures contamination from powder gases constitutes a twofold problem. If the gases are condensable, they immediately appear either on walls and window surfaces as "snow" or "frost" of various kinds or as a fog presumably made up of fine crystals of unknown composition. The fog does not settle out during moderate lengths of time so the result is a working medium with poorly known physical constants which is also optically of poor quality. During recent firings at low temperatures, the baffle systems plus improved techniques of flushing the gun chamber after firing have minimized problems caused by frost or fog; nevertheless after ten rounds have been fired from the .75-cal. launcher some frost can be observed at the station windows, and fog, though slight, is easily detectable.

An interesting result in the $K_D$ vs. $M$ curves for the blunt cone-cylinder has emerged as improved techniques have provided smoother data. In the region near $M = 4$ a slight bump appears which extends over about half a Mach Number. This phenomenon was first noted in the data obtained from firings through nitrogen at low temperatures.[7] More recently firings at room temperature through argon-sulfurhexafluoride mixtures[11] have revealed the same hump in the curve. So far no explanation for its presence can be given.

### *Interferometric Properties of the N-Wave*

A shadowgraph or interferogram of an axisymmetric flow presents an enormous amount of data in visual form. Attempts to reduce these data to quantitative results emphasize the desirability of principles which correlate whole areas of flow under a single unifying law.

Some years ago the discovery was made[12] that conical flows demonstrate an unusual and simplifying symmetry for interferometric purposes. The gist of this principle is that fringe shift $\delta$, divided by axial distance $z$, is a unique function of $r/z$ throughout the entire conical flow. Here $r$ denotes distance in the radial direction. Plots of $\delta/z$ vs. $r/z$ yield a single curve in conical flows and may be used as "test gages" to determine whether a flow is conical and where it departs from conicity. This conical flow principle has been used successfully as a tool in studying other related flows.[13, 14]

Recently a similar principle has been found to hold in the distant flow between the front and rear shocks caused by an axisymmetric, supersonic projectile. Along a trace parallel to the axis, this region is characterized by a vertical pressure rise at the front shock followed by a linear decrease to below ambient levels and finally another vertical pressure rise at the rear shock. Because of this N-shaped pressure curve, the region has been called "the N-wave."

Theoretical studies by G. B. Whitham[15] have given approximate expressions for the pressure in the N-wave region. Working to the same approximation, D. H. Steininger[16] and the author[17] have derived expressions for the interferometric fringe shift in the N-wave and compared these to data from cone-cylinders and spheres. When suitable approximations are applied, a simple mapping function is obtained which characterizes N-wave flow. If $\xi$ represents the fractional distance between front and rear shocks along a trace at constant radial distance $r$, then it can be shown that $\delta r^{1/3} G' = \xi^{1/3}(1 - 4\xi/3)$; thus by plotting $\delta r^{1/3} G'$ vs. $\xi$, ex-

perimental data can be compared with the function $\xi^{1/2}(1 - 4\xi/3)$. $G'$ is a function which depends upon Mach Number, body shape, the wavelength of light used, and physical constants of the medium. Convergence to N-wave flow has been examined for a cone-cylinder of 7.5° half-angle and for small spheres. At 70 diameters from the axis of the sphere the agreement between plotted fringe shifts and the mapping function is excellent, and one concludes that N-wave flow is obtained.

Not only may fringe shifts within a given region of flow be compared by means of this principle but also fringe shifts from flows about similar bodies at different Mach Numbers and under different conditions of ambient density. This latter is a direct consequence of the fact that the function $G'$ accounts for differences in Mach Number, density, etc. It is perhaps apparent that interesting studies of N-wave flow as a function of Reynolds Number might now be undertaken.

The N-wave mapping law yields a principle which permits study and comparison of axisymmetric flow data over a large region of the flow. It holds this property in common with the conical flow principle. Reasoning by analogy one may expect that the N-wave property will eventually become useful as a diagnostic criterion and standard of comparison in the same way that the conical flow test already has done.

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## Liquid Rocket Propellants (Continued from page 58)

what is probably more nearly correct, developing precise and reliable power plants around these rocket propellants—are solid problems albeit not insurmountable. A discussion of the general problem areas in this application field is regrettably beyond the security level of this paper.

Is there an energy limit to "molecular" rocket propellants? There is. The limits are set up by the natural and inexorable laws of chemistry and physics which I am reasonably sure cannot be breached. Molecular dissociation, molecular weight, and molecular bond energies are the triple agents at the energy barrier. However, in 1957 we are not yet at the break-off point and we may feel free to contemplate with confidence new energies of higher specific impulse than are available to us today.

"*. . . highly developed theory is of minor use. . . .*"

# System Considerations in Instrument Dynamics

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THE ISOLATION of the pilot in a modern aircraft grows ever more complete as we make him fly under conditions that divorce him from sensory perception of his ambient world. Our remedy is to supply him with computers for those of his functions not involving command decision and to improve his instrumentation. Since a computer requires instrumentation, as does the pilot, the technique of instrumentation has a record of continuing progress.

These improved instruments have reached new heights of static accuracy and sensitivity. Altimeters of 1/4 per cent accuracy and a few inches sensitivity, machmeters of a few thousandths of a Mach Number accuracy and a sensitivity measured in millionths of a Mach Number, angle of attack sensors that measure to fractions of a degree, all are available; all will maintain these accuracies under military field tactical conditions.

But, as opposed to these static accuracies, the dynamic accuracies grow ever more unsatisfactory. For one thing, less responsive aircraft, with response sacrificed for performance, require faster response from instruments for the same maneuvers. Air-frame stability is to a degree being charged to the instruments, and, with such stability being a matter of life itself, minute phase lags have become important. The computers and the electronic and electromechanical circuits can be made to have any reasonable response; it is in the systems aspects of the instrumentation that the dynamic effects appear. In what might be called "self-contained" instruments like gyro stable platforms, the problems are intrinsic and will not be considered. But in measurements of air-stream angles, pressures, and pressure ratios, the problems are amenable to system thinking.

Consider the measurement of angles of attack and sideslip. The art of measurement of these angles has progressed rapidly until at the present time a wide variety of equipment is available, supplying static angular accuracies in almost any necessary tolerance. Probably the most used solution for precision angle of attack is the computer solution, which uses no external sensors to provide an indication of angle but computes the value from the parameters of the aircraft itself. Recently, however, the external sensor, long used for crude indications of local angle, has been growing in popularity as a means of measuring local angle of attack with high precision. The local angle is then used as an input to a computer whose output is true angle of attack. The static errors of such computer-sensor combinations are a function of their size, cost, and standards of workmanship and design. The dynamic errors are not as fully understood and have not been widely disseminated in publication.

The average sensor consists of a mass rotating about an axis in such a manner as to align itself with the air stream. The actual mechanics of alignment will vary, depending upon the design of the sensor. In any case, some equivalent inertia about a rotating axis exists and some restoring torque about this axis will exist and be a function of the difference between the sensor position and the position it would assume in the steady state. This difference, expressed in terms of wind direction angle, may be termed the dynamic error of the sensor proper. It does not necessarily coincide with the error of wind angle of the aircraft, as will be seen.

Consider a weathercocking vane, set to measure indicated angle of attack. It rotates about an axis parallel to the pitch axis of the aircraft and, for purposes of explanation, we shall consider the angle between the fuselage reference line and the direction that the vane is "pointing" as the indicated angle. We shall assume that there are no static errors to be considered—i.e., in the steady state that the vane "points" in the direction of the relative wind. This system is typical of several sensors in use today. The inertia and torque developed by such a vane can be measured. A photograph of a commercially available unit of this type is shown in Fig. 1. Typically, both torque per angle of

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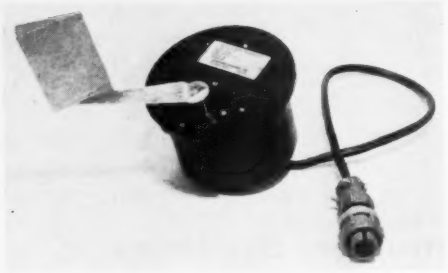

FIG. 1. Relative wind transducer, weathercocking type.

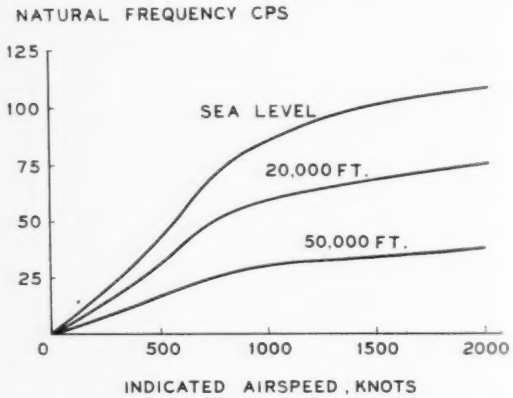


FIG. 2. Typical vane characteristics.

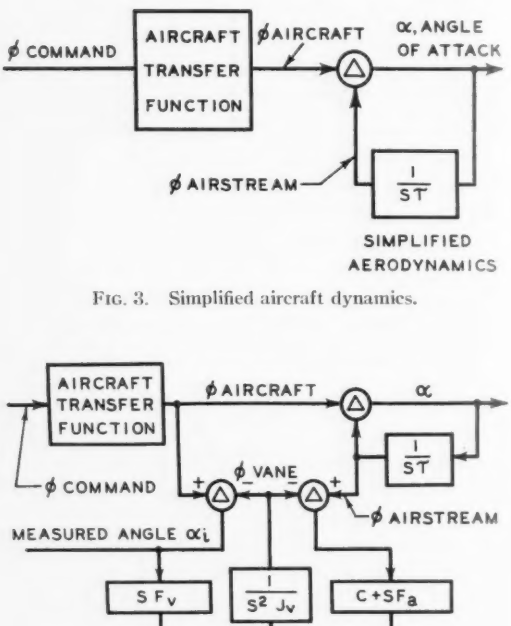


FIG. 3. Simplified aircraft dynamics.

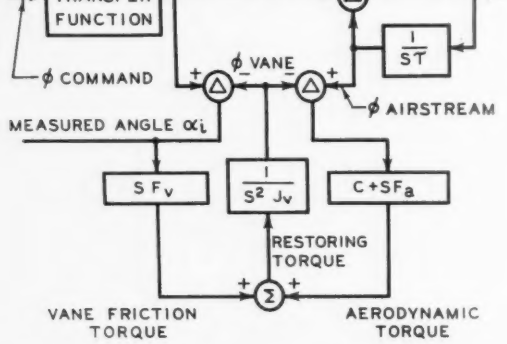


FIG. 4. Vane dynamics.

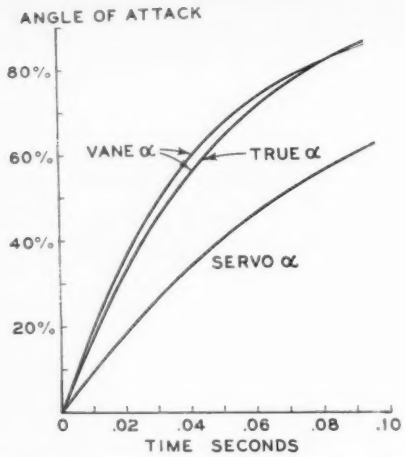


FIG. 5. Response of typical matched weathercocking, mismatched weathercocking, and servoed vanes to a changing true angle of attack.

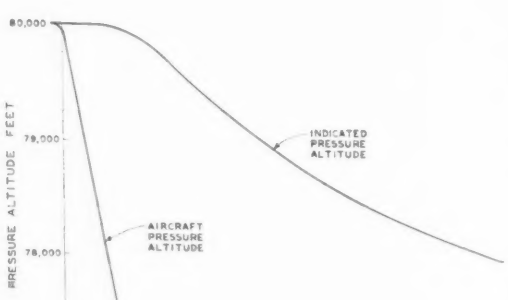


FIG. 6. Indicated and true altitudes during a typical maneuver.

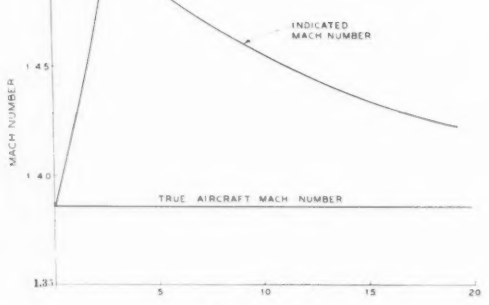


FIG. 7. Indicated Mach Number during a constant Mach Number dive.

vane error and rotational inertia have been increased by mounting the sensing airfoil on a lever arm. If we consider the restoring torque to be directly proportional to the angular displacement from wind direction, then the vane and its associated inertia and friction, assumed viscous, form a typical second-order system with a single mode of oscillation—i.e., one natural frequency and damping ratio. Actual sensors closely approach this condition. The value of the restoring torque and hence the value of the natural frequency and damping ratio vary with the aerodynamic conditions in common with those of any airfoil used over the wide ranges of one such as this. The one shown in Fig. 1 operates from low subsonic to high transonic Mach Number with the natural frequencies shown in Fig. 2.

Now a laboratory test can be devised to measure these natural frequencies and damping ratios, either directly, in a wind tunnel, or by simulating restoring force. Such a simulation test does not account for the aerodynamic damping and the drag damping due to dissipation of vane energy in the air stream and must be applied with caution. But in either case, no matter how accurate the measure of the vane natural frequency and damping, it does not directly provide indication of the dynamic effects of the vane as an angle-of-wind-direction measuring device. Thus, at, say, 10 cycles per sec., the response of the vane may be only 1/2 its steady-state response, but with a 10 cycle per sec. variation of angle of attack, there may be no deterioration whatsoever in indicated angle of attack.

This seeming discrepancy comes about because the wind direction measured by these vanes is not a true wind, but rather the relative wind caused by motion of the aircraft through the air. In addition, the aircraft cannot immediately assume a new direction of motion. These effects may be examined by considering a vane on an aircraft turning in pitch. Assume then that an aircraft traveling in some direction applies control action and rotates the aircraft to a new pitch angle. This will change the angle of attack between the aircraft axis and the direction of travel. The changed lift force will change the direction of travel of the aircraft by acting on the aircraft inertia.

If this aircraft has a freely floating vane, weathercocking into the wind, as the aircraft makes the turn the vane will tend to remain pointing in its original direction in space due to its moment of inertia. But this will make it indicate the correct wind angle immediately. It can be seen that a high inertia to friction force ratio will actually improve the frequency response, as long as the time constant of the system is shorter than the rather long time constant in turning of the aircraft. It can also be seen that a free-floating vane—i.e., one in which all rotating masses are rigidly connected and rotate through the same angle as the incident air stream—will have a considerable advantage over sensors which carried geared inertias. Any geared or linked inertias on the vane will stop the vane from performing its most important function—that of sitting still when the aircraft revolves around it.

These remarks can be investigated further by drawing a signal flow diagram and putting in the transfer functions and the ratios of the Laplace transforms of the input and output time functions. This is shown in Fig. 3.

Here a command is shown as acting upon the aircraft to move the aircraft until it assumes an angle in pitch of $\phi_{\text{aircraft}}$ from the horizontal. The difference between this and $\phi_{\text{air stream}}$ is the angle of attack. Now, $\phi_{\text{air stream}}$ is the angle between the horizontal and the velocity vector. A change in angle of attack changes the lift force which gives a rate of change of vertical velocity, which gives a rate of change of $\phi_{\text{air stream}}$. A simplified transfer function, $1/s\tau$, expresses the relationship between these angles where $s$ is the Laplacian operator for $d/dt$ and $\tau$ is a constant.

More elaborate and more correct aerodynamics would certainly be used in a strict analysis, but our purpose is heuristic. To this diagram we add the vane dynamics of Fig. 4. We introduce $C$, the vane restoring torque as a function of the angle of vane airfoil incidence; $F_a$, the vane aerodynamic viscous drag coefficient; $J_v$, the vane moment of inertia; and $F_v$, the mechanical viscous friction coefficient of the vane pivot.

The signal flow diagram is easier than the corresponding equations in demonstrating the various relationships and is easily reduced to the corresponding transfer ratio between any variables. In this case, the ratio $\alpha_i/\alpha$ (or, more accurately, the ratio of their Laplace transforms) is desired since it represents the degree of erroneous indication, $\alpha_i$ being the indication of the vane, while $\alpha$ is the true angle

$$\frac{\alpha_i}{\alpha} = \frac{s^2 + s\left[(1/\tau) + (F_a/J_v)\right] + (C/J_v)}{s^2 + s\left[(F_v/J_v) + (F_a/J_v)\right] + (C/J_v)}$$

Now, $1/\tau$ is the rate of change of the aircraft velocity vector per unit angle of attack. The interesting fact is that if this $\tau$ is made equal to the vane time constant $J_v/F_v$, then the indicated angle equals the true angle and dynamic effects cancel out.

A more elaborate analysis shows $\tau$ to be approximately what is called the aircraft pitch time constant. Matching the vane time constant to the aircraft pitch time constant is necessary to provide correct dynamic response. The vane time constant is the mechanical time constant not varying with atmospheric state. Unfortunately, the pitch time constant does vary, so the matching cannot be invariant.

Note that only the free-floating sensor can have these dynamics. Internally geared or linked or servoed (mechanically, pneumatically, or electrically) sensors cannot "remain still and let the aircraft rotate around them." They must be dragged to the new position and fight their way back. Note also that changes in $F_a$, the aerodynamic viscous damping, will not affect the match. It is feasible, therefore, to increase this damping and make the vane relatively insensitive to the rapid fluctuations due to gusts. This can be done, to a degree, by proper choice of the airfoil making up the vane or, in

addition, by placing on the vane shaft a hollow flywheel filled with a viscous fluid and containing a free-floating body—i.e., by coupling the vane through a viscous fluid to a free inertia. These "flywheel dampers" are easily made of real fluids or their equivalent magnetic fields. They can damp out gust effects and minimize the effects of mismatch since it is really the quantity $(J_v/\tau) + F_a$ which is being matched to $F_v + F_a$. Accurate aerodynamic representation shows that this effect is not too helpful since $J_v/F_a$ must stay smaller than $\tau$ for the matching condition to hold. Fig. 5 shows responses obtained when actual values are assumed for some of the variables.

The case of static pressure lags is simple and is easily understood although rarely believed by most persons. A static pressure system consists of pneumatic volumes connected with orifices and tubes. While the writer has seen laboratory measurements made on such systems, such measurements are rarely valid because the limiting orifice appears to be the orifice in the pitot-static head, and there seems to be no general agreement as to the pressure drop through this orifice when immersed in a moving air stream, although it is the practice to express fears that this may be much greater than the corresponding drop when the aircraft is standing still.

Nevertheless, the computation serves to illustrate certain pertinent facts: first, that the time constants are much longer than is commonly suspected and, second, that the time constant varies approximately inversely with pressure. A typical system using instrument tubing of 3/32-in. inside diameter of typical lengths and volumes will have a time constant of 1/2 sec. at sea level, lengthening to 15 sec. at 80,000 ft. of standard altitude. The meaning of such a lag can be seen by a plot of the pressure in the altimeter case for an aircraft at 80,000 ft., traveling about Mach 1.4, that noses down into a 45° dive and pulls out rapidly 3,000 ft. below at an essentially constant rate of dive. Fig. 6 shows the maneuver as it occurs and as it appears on the altimeter. The numerical values used in this calculation are from an actual installation. The obvious improvement is to make the pressure tubing larger; as a matter of fact, when the tubing volume is small compared to the fed volume, the fourth power of the diameter enters into the equation. Going from 3/32-in. to 3/16-in. inside diameter tubing will bring the time constant from 15 sec. to less than 1 sec. But this calculation uses an experimentally verified equation which calculates time constant for a volume fed through a long tube. Not included is the effect of the (often minute) orifices in the static head and the head volume, as well as the aforementioned "dynamic clogging" which is not as yet, to the writer's knowledge, experimentally determined. The curves may thus be assumed to have a throw-up-one's-hands validity.

As a practical, immediate necessity, what can be done about it? The instrument maker can improve the instrument until its time constant is negligible, but actually the pressure on the manufacturer is in the other direction. Present static pressure systems are showing undamped "organ pipe" resonances of the order of 3 cycles per sec. at normal ambient temperatures, climbing to 6 or 10 cycles per sec. at elevated temperatures of high-speed flight. Since no good system of preventing these resonant oscillations without greatly increasing the time constant has been developed, it is usually required that the time constant of the altimeter proper be at least 1/2 sec. At low altitudes this is usually the determining delay.

Since accurate altimeters use the servo balance or force balance principles, it is possible to use electrical differentiation and obtain a signal proportional to rate of climb. Unlike the "leaky bellows" type of instrument, this signal has essentially zero lag behind indicated altitude. It may thus be used as a corrective signal to cancel part of the dynamic error. In advanced air data computers this signal compensates for part of the pressure lag and, in a constant-rate dive, can eliminate all lag error, in theory. But although steady-state velocity errors are eliminated, transient errors are not, and lag errors occur upon entering or leaving a dive and, in general, during maneuver.

In the case of Mach Number, the transient can occur even if Mach Number does not change. Mach Number is calculated from the ratio of static pressure to differential pressure, where differential pressure is the difference in absolute pressures of the static and the pitot lines. The usual Mach Number sensor has two capsules for sensing pressure. One is evacuated and sealed; the other is connected to the pitot line and has indicated total pressure inside. The case surrounding both is filled with static pressure. The force exerted by the evacuated capsule is thus proportional to static pressure and the force exerted by the other is proportional to the differential pressure. Their ratio can then be measured. Because of this almost universally used arrangement, the static volume (i.e., the case volume) is of the order of 20 to 100 times the pitot volume (i.e., the capsule volume). Hence the lag of the static measurement is many times that of the pitot measurement. Thus, although the ratio of static to differential pressure may remain unchanged in the pitot-static head, their varying lags may result in a widely varying ratio in the instrument case.

A typical example, using numerical values from an actual installation, is shown in Fig. 7. Here an aircraft dives from 80,000 ft. to 77,000 ft. of standard altitude at constant Mach Number. The Mach Number indicated by a perfect lag-free instrument is shown.

The remedies for all these errors are obvious, difficult, and honored in the breach. Since angle of attack systems have separate distinguishable dynamic responses, specifications can be written requiring just this testing. Aerodynamic forces can be simulated with springs in the case of vanes; otherwise a wind tunnel can be used. The body of the sensor should be rotated through an angle sinusoidally or with some other test signal. Any motion of the sensor out of alignment with the air stream

(*Continued on page 84*)

*The contributions of the dynamic properties of the thrust chamber, propellant lines, and pumping system to the stability and controllability of the rocket power plant are explored. Particular attention is given to the extent of understanding contained in the literature.*

# Effect of Dynamic Characteristics of Rocket Components on Rocket Control

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Lewis Flight Propulsion Laboratory, NACA

SYMBOLS

| | | | |
|---|---|---|---|
| $C$ | = capacitance | $t_d$ | = dead time |
| $K$ | = loop gain | $\delta$ | = deflection |
| $L$ | = inductance (inertia) | $\zeta$ | = damping factor |
| $P$ | = pressure | $\tau$ | = time constant |
| $Q$ | = flow | $\omega$ | = frequency |
| $R$ | = resistance | *Subscripts* | |
| $s$ | = Laplace operator | 1 | = input |
| $t$ | = time | 2 | = output |

## INTRODUCTION

THE EFFECTS of the dynamic characteristics of the components of a rocket propulsion system should be understood because they influence the control requirements, the propulsion system weight, and the overall proportions of the vehicle.

Missile weight considerations tend to force a selection of a low injection pressure drop in order to minimize pump delivery pressure for a given thrust chamber pressure. The weight of the propellant feed system—including piping, pumps, turbine, and gas generator—increases almost proportionately with pump delivery pressure, and since in some missiles the propellant feed system is a large portion of the mass of the vehicle at the end of the power-on trajectory, an increase in take-off weight of as much as 15 lbs. for every pound of pump weight may be incurred. This creates a serious design problem because the rocket propulsion system, consisting of the thrust chamber and propellant feed system, tends to become unstable as injection pressure drop is decreased.

**This work is revised and condensed from the paper of the same title presented at the Rocket Propulsion Session, IAS 25th Annual Meeting, N.Y., Jan. 28–31, 1957. The original work still is available as IAS Preprint No. 710.**

**The authors are Chief, Head of Section A, and Aeronautical Research Scientist, Dynamics and Controls Branch, respectively.**

## NATURE OF STABILITY PROBLEM

A basis for understanding the nature of the instability may be achieved by examining a simple system consisting of a thrust chamber fed from a large pressurized propellant tank and having a very short line from tank to injector, as shown in Fig. 1. In this case the pressure $P_1$ ahead of the injector can be considered constant, but the chamber pressure, and consequently the pressure drop across the injector, can fluctuate quickly with changes in combustion. Thus, a disturbance in chamber pressure causes a change in propellant flow, which in turn causes another disturbance in chamber pressure.

This amplification of a pressure disturbance can be shown (after Lee, Gore, and Ross[1]) to be

$$K = -\frac{P_c}{2(P_1 - P_c)} = -\frac{\text{chamber pressure}}{2 \times \text{injector pressure drop}}$$

This equation shows that reductions in injection pressure drop to save pump weight increase the loop gain. Consequently, any fluctuation or "noise" in the chamber pressure is amplified, and the system can be unstable.

Not only does the desired low injection pressure drop promote instability, but the accompanying high loop gain makes the system extraordinarily sensitive to otherwise minor factors, such as elasticity of the vehicle structure, pump case, lines, and injector.

## DYNAMIC CHARACTERISTICS OF SYSTEM COMPONENTS

The propulsion system studied is shown in Fig. 2 and represents one side of a typical bipropellant rocket system. A turbine-driven pump draws fuel from the tank and delivers it through the injector to the thrust chamber. Thrust level is controlled by a throttle valve in the line from the gas generator to the turbine.

The dynamics of the various components of rocket propulsion systems have been investigated and reported in the literature. Dynamics of the combustion and aerodynamic processes in the thrust chamber have been measured and reported by investigators at the Jet Propulsion Laboratory of the California Institute of Technology,[2] Princeton University,[3] and elsewhere. An idealization of their findings is shown in Fig. 3.

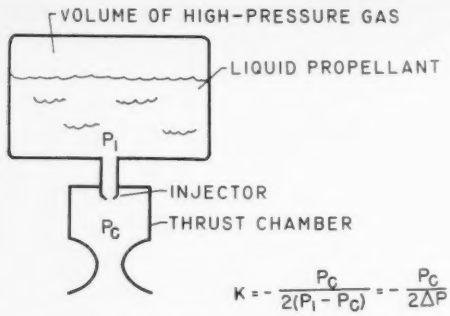



FIG. 1. Tank-fed rocket thrust chamber.

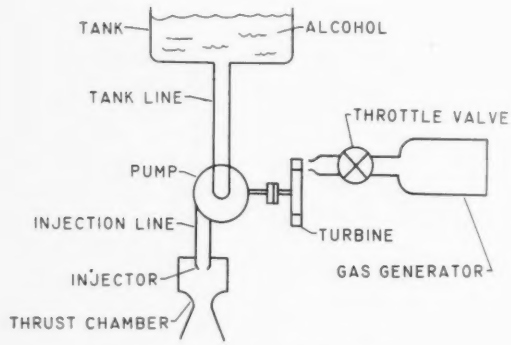



FIG. 2. Rocket propulsion system.

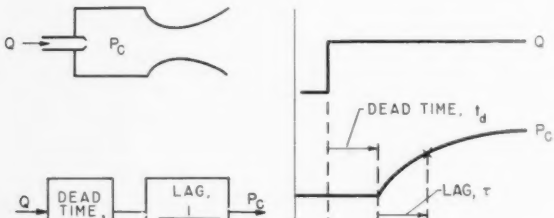



FIG. 3. Dynamics of the thrust chamber.

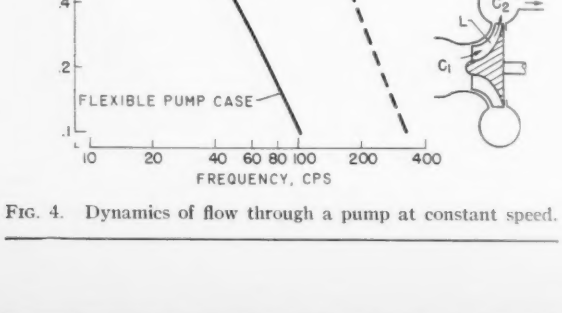



FIG. 4. Dynamics of flow through a pump at constant speed.

If a sudden increase in propellant flow occurs, a period of dead time of about 0.003 sec. elapses with no observable change in chamber pressure. Then the chamber pressure rises exponentially to the final steady-state value. This exponential rise can be measured by a characteristic time constant, which in this case is also about 0.003 sec. The dead time is a combustion phenomenon, and the lag is an aerodynamic property of the shape of the thrust chamber.

Discussions in the literature of fluid transients in pumps have not been found by the authors. Consequently, in this study the electric circuit analogy shown in Fig. 4 was used to represent the pump. $C_1$ is the elasticity (or capacitance) of the fluid and the pump case at the inducer section, $L$ is the inertia (or inductance) of the fluid in the impeller passages, $R$ is the steady-state relation between pressure differential and flow at constant pump speed, and $C_2$ is the elasticity of the fluid and the pump case at the outlet diffuser section.

Since no dynamic data on pumps were available, the constants were first calculated with the use of dimensions from rocket turbopump and the elasticity of the fluid, with the pump case assumed to be rigid. The frequency response using these constants is shown by the dashed curve in Fig. 4. A rough measure of the total capacitance ($C_1 + C_2$) of the pump was made experimentally by blocking off the inlet and outlet, filling with fluid of known compressibility at high pressure, and measuring the amount of fluid that must be removed to reduce the pressure to atmospheric. This measurement yielded a capacity about 50 to 70 times that expected from fluid compressibility alone. The calculated frequency response using the experimentally measured values is also shown in Fig. 4. This curve indicates that the elasticity of the pump case significantly affects pump dynamics at frequencies above 40 cps.

For this study the propellant lines were considered analogous to electric transmission lines. Capacitance due to fluid compressibility and elasticity of tubing walls, inductance due to fluid inertia, and resistance due to wall friction can be calculated. Thus, lumped constant networks similar to the one used to represent the pump (Fig. 4) can also be used to represent the lines. The response of this type of network, however, provides a good approximation of line dynamics only up to about one quarter of a wave length (the wave length as determined by acoustic velocity in the fluid and maximum frequency of interest). The tank line (Fig. 2) was therefore represented by three lumped constant sections and the injection line by one section.

Although the injector was considered as simply a resistance to flow during most of this investigation, a brief study of injector elasticity or capacitance was also made. From a procedure similar to the experimental determination of pump capacitance, it was determined that the injector might have a capacitance of about 25 times the capacitance due to the compressibility of the fluid it contains. Essentially all of this

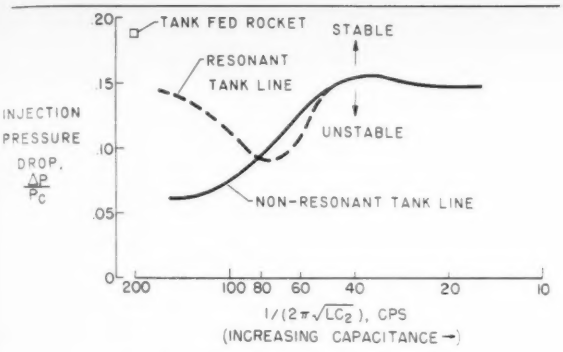



FIG. 5. Effect of pump capacitance.

capacitance was attributed to elasticity of the injector face.

## DISCUSSION OF RESULTS

The complete propulsion system may now be studied from the point of view of stability, amplification of noise, and sensitivity to secondary influences. In order to facilitate this study, the propulsion system components were simulated with an electronic analog computer. Details of the dynamic equations, calculations, and analog computer simulation are given in the appendix of reference 4. One of the purposes of the study was to determine means of reducing injection pressure drop, and thus reducing required pump delivery pressure and overall system weight, while still maintaining stable operation. Refinements of the excellent work of other investigators (Lee, Gore, and Ross[1]; Marble and Cox[5]; and Sabersky[6]) were made by including the dynamics of fluid pressure transmission through the pump.

In the following discussion of the effects of component dynamics on the behavior and controllability of the propulsion system, the minimum permissible injection pressure drop will be used as a criterion of excellence.

As a preliminary, it should be reported that a control regulating the hot gas that drives the turbopump is powerless to influence the relatively high-frequency instability herein investigated. This conclusion is in agreement with control studies reported by B. N. Smith[7] and Gore and Carroll.[8]

The characteristics of the pump have a marked influence on the stability of the system. Tsien[9] and Marble and Cox[5] show that, as the pump flow is made less sensitive to delivery pressure, the system is generally more stable. The effect of capacitance of the pump diffuser and inducer on permissible injection pressure drop is shown in Fig. 5. The capacitance is expressed in terms of the resonant frequency $1/(2\pi\sqrt{LC_2})$, where $L$ is the injection line inductance, and $C_2$ is the pump diffuser capacitance. The inducer capacitance is varied simultaneously and proportionately. The figure shows that reducing pump capacitance can stabilize the system and reduce the required injection pressure drop materially, provided that the tank line is not of such length and inductance that it is resonant with chugging frequency.

Dynamic properties of the propellant lines have been shown by experiment (Lee, Pickles, and Miesse[10]) and by analysis (Sabersky[6]) to exert great influence on system stability. For example, the principal effect of the injection line system on stability is due to resonance phenomena. The line impedance exhibits a series of resonant peaks and nodes, which are functions of line length and disturbance frequency. Thus the line can help either stabilize or destabilize the system, depending on its length. This property has been analyzed by Sabersky.[6]

Improvement in performance can be achieved by increasing the inductance of the injection line, as suggested by Lee, Pickles, and Miesse.[10] In the present study the effect of increasing inductance (by reducing line diameter and thereby increasing the velocity in the line) is shown in Fig. 6. As may be seen, an increase in inductance (flow velocity) above the nominal value of 15 ft. per sec. produces a significant reduction in required injection pressure drop. This reduction is offset in a measure by the friction pressure drop in the line that will accompany high velocities. Longer lines will show similar improvement, provided resonances are avoided. Thus careful selection of injection line size may result in improved stability and low injection pressure drop. The original choice of line size made for this study provided practically no stabilization.

Effects of tank line inductance (velocity) on stability are shown in Fig. 7 for a system with an electric pump case and a system with a rigid pump case. With a rigid pump, increasing tank line inductance (velocity) produces a large stabilizing influence, except for a bad resonance at a velocity of about 15 ft. per sec. If the elasticity of the pump measured for the study is included, the tank line inductance provides no stabilization.

If the elasticity of the injector provides significant additional capacitance, as indicated by preliminary measurements, then the injector inlet capacitance would

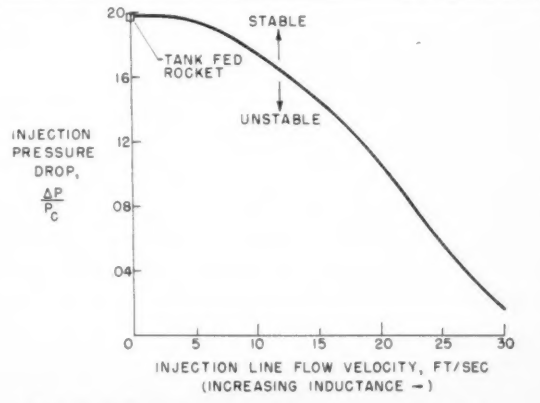



FIG. 6. Effect of injection line inductance (velocity).

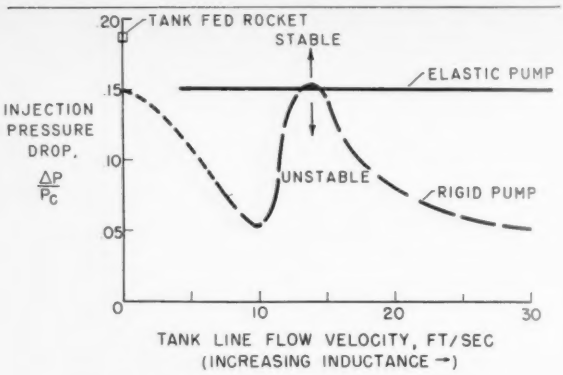



FIG. 7. Effect of tank line inductance (velocity).

tend to isolate the thrust chamber from the injection line and diminish the stabilizing effect of the injection line inductance. On the other hand, the injector face elasticity would tend to decrease the effect of changes in thrust chamber pressure on flow—and thereby stabilize the system.

It is apparent from the information presented thus far that the performance and stability of the propellant supply system are influenced greatly by a number of factors that might be considered minor, such as elasticity of the injector. Such results might be expected since operation as near the limit of instability as possible is desirable because the lightest weight pumps are then possible.

It is also necessary to point out that modulating the thrust to a low value by reducing the flow from the pump reduces the injection pressure drop much more than the thrust chamber pressure, thus making the system more unstable.

Consider now what beneficial stabilizing effects can be obtained from control. Several control systems capable of high-frequency operation have been proposed. Tsien[9] and Marble and Cox[5] propose a control as shown in Fig. 8(a). Thrust chamber pressure is sensed, and a piston is moved to inject or extract fuel from the fuel line at the injector in such a manner as to maintain a constant pressure drop across the injector. The second control, proposed by Li,[11] is shown in Fig. 8(b). Flow of propellant to the injector is measured, and a throttle is moved to suppress high-frequency fluctuations in flow. The injector itself could be used as a flow metering orifice.

Both of these controls have the action of reducing loop gain of the thrust-chamber-propellant feed system loop for a given pressure drop and could stabilize the system, even at zero pressure drop across the injector.

Transfer functions have been calculated for these controls so that the system can be made unconditionally stable. However, the required transfer functions are quite complicated, and it was therefore considered practical to investigate the action of a simple second-order servo operating the throttle control of Fig. 8(b).

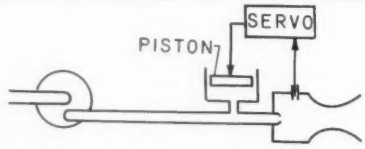
The difficulty in achieving such control lies in the required speed of response of the control; it must act at frequencies well above 75 cps, the natural oscillation frequency of the thrust chamber. Fig. 9 shows the effect of control resonant frequency on required injection pressure drop. These data were obtained with the nominal pump capacitance divided by 10. A resonant frequency of at least 75 cps is needed. Slower controls can be worse than none.

The ability to construct such high-frequency controls can be questioned. Such controls having resonant frequencies of 300 cps have been constructed by Otto, Gold, and Hiller[12] but of much lower flow capacity than that needed for rockets.

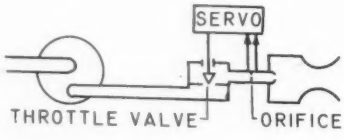
Another disadvantage of these controls is that the flow loss in them may be greater than the reduction in injection pressure drop made possible by them. This objection should not be so significant in systems operating at high thrust chamber pressures as in those operating at low thrust chamber pressures.

## Conclusions

In summary, attention should be refocused on the fact that weight considerations force the choice of such a low injection pressure drop that danger of oscillation or "chugging" is present, and the system is sensitive




(A) PRESSURE FEED BACK TO A PISTON.




(B) FLOW CONTROL.

FIG. 8. High-frequency stabilizing controls.

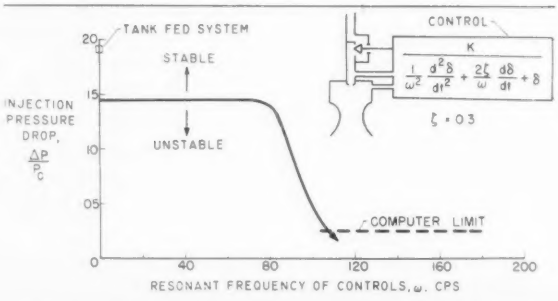



FIG. 9. Control system resonant frequency requirements.

to adverse effects of otherwise insignificant factors, such as elasticity of the pump case, lines, and injector. Significant improvements in stability can be achieved by increasing the flow inertia or "inductance" of the propellant lines, provided harmful resonances are avoided. High-frequency control of propellant flow at the injector can remove the instability, thus making possible the selection of an injection pressure drop as low as is consistent with combustion requirements.

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*Based principally on jet airplanes, this study considers the various flight paths which can be utilized during VTOL and the resulting aerodynamic, gyroscopic, and inertial influences on the airplane.*

# Problems of Stability and Control for VTOL Aircraft

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Bell Aircraft Corporation

## Introduction

In the case of conventional aircraft, stability and control have been primary factors in design. In the case of the VTOL, it is mandatory that early consideration be given to these problems. Complex dynamic relationships exist in the unconventional flight regimes where these airplanes must operate. The magnitude of these problems is severe enough to cause a configuration to lose its idealized performance if they are not considered.

Bell Aircraft has been principally involved in this field ever since it built and flew the first jet-propelled VTOL airplane 3 years ago. The airplane was called the air test vehicle and is shown in Fig. 1. The design and construction were financed by Bell Aircraft with Air Force support in the form of engines. Since that time, Bell Aircraft funding has been supported by both the Air Force and the Navy in continuous design of other jet and ducted propeller types. The recently released USAF X-14 airplane is shown hovering in Fig. 2.

## General Requirements

It is important to realize that each type of VTOL/STOL aircraft has its own specific characteristics of stability and control during take-off and landing. It is almost impossible to generalize the problem except to delineate the areas where these airplanes must operate.

(1) They must hover at zero forward speed, over a spot, with good precision, and with a capability for good maneuverability in all weather conditions.

Fig. 1. Air test vehicle hovering.

(2) They must be capable of vertical ascent and descent to cross surrounding obstacles and make use of extremely small landing sites.

(3) They must effect a transition from the hovering condition to a speed above level flight stall speed.

(4) They must perform a useful mission in terms of speed, radius of action, and pay load. This is not an insignificant part of the operation.

(5) They must decelerate from level flight condition at stall speed to a hovering condition.

(6) They must descend from hovering to a vertical landing in a limited site with precision in stabilization and a good capability for maneuver.

Fig. 2. X-14 VTOL airplane hovering.

**This work is revised and condensed from the paper of the same title, presented at the VTOL-STOL Aircraft Session, IAS 25th Annual Meeting, N.Y., Jan. 28–31, 1957.**

**The author is Chief, Aerodynamic and Propulsion Design Department, Aircraft Division.**

This set of requirements immediately imposes the necessity for operation in three varied flight regimes where:

(1) Velocity of the free stream is zero and aerodynamic parameters of the aircraft are insignificant because of their dependence on this velocity function. Inertia terms and external forces are of paramount importance.

(2) Aerodynamic forces are appreciable but insufficient for level flight. Here the aerodynamic and inertia forces are intermingled on a par.

(3) Aerodynamic forces are predominant. This is the conventional level flight condition with its customary problems plus such additional compromises as may result from the large thrust or other features imposed to obtain VTOL.

Because of the broad nature of the problems of stability and control, it is easier to examine characteristic examples of several different types of airplane than to generalize the problems. This paper is based on several representative studies which will demonstrate the problems to be expected in several areas. The basic approach is to examine one airplane as both a tail-sitter VTOL and a horizontal-attitude VTOL.

Experience at Bell Aircraft has been principally directed toward horizontal-attitude VTOL. In addition to obvious operational advantages, this approach appeared to have substantial stability and control advantages when compared to the tail sitter. Our major design effort has been pointed toward optimizing this type of VTOL; and it is possible that this same aircraft will not reflect the best design effort which has been applied to a tail sitter. The exercises in this paper will reflect the problem which may be anticipated.

A hypothetical design might be visualized as weighing 25,000 lbs. Assuming a jet aircraft, since the lack of the propeller slipstream across the wing simplifies the angle of attack, the problem may be examined by following the flight paths for take-off and landing.

### Fixed Thrust or Tail-Sitter VTOL

In the case of the tail sitter, the airplane is rotated up on its tail and launched by applying a sufficient amount of thrust. It can then climb vertically and hover on its jet. From the hover the tail sitter may accomplish transition into level flight by two obvious flight plans. It can accelerate straight up until it obtains sufficient velocity on the wing and tail surfaces to "fly over" into horizontal flight. On the other hand, it can also "push over" immediately from the hover by trading its supporting thrust for the build-up in lift on the wing surface. The stability factors involved can be examined by observing the hypothetical design as it passes through these cycles (Fig. 3).

### Fixed Thrust - Low Angle of Attack Take-Off

In the trajectory type of take-off, it is necessary to accelerate the airplane upward against the pull of gravity. If this can be done, the airplane can execute a transition at a low angle of attack. Since turbojet engines lose thrust with altitude and acceleration is directly dependent on the thrust-to-weight ratio available, an excess thrust margin will be required at start of take-off if this transition is to be executed in a reasonable time period. If a limited thrust is available in the aircraft, then obtaining the excess thrust-to-weight ratio requires that the potential fuel load be reduced. If the fuel load is not reduced sufficiently and the thrust-to-weight ratio is lowered, then the airplane experiences a lower accelerating force and requires a longer time to get level flight velocity. This increase in time required for take-off combined with the high fuel consumption of the jet engine results in a somewhat asymptotic increase in fuel consumption. The reduction of fuel available for the mission is an obvious result.

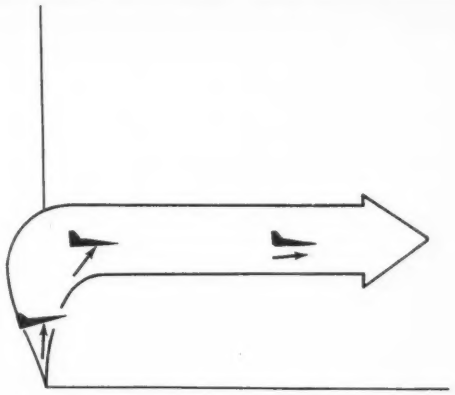

Fig. 3. VTOL tail sitter take-off flight paths.

### Fixed Thrust - High Angle of Attack Take-Off

It can be seen that the use of the low angle of attack take-off on a trajectory path can be expensive in terms of fuel consumption. The alternative approach involves the slow vertical rise and "push over." Actually, an extremely small thrust margin is required to accelerate an airplane vertically to a velocity of 5 to 10 ft. per sec. Low speeds are quite sufficient for breaking ground and rising to hover. The use of afterburning or nonafterburning turbojets provides the burn-off of fuel so fast that one can essentially operate from an initial $T/W = 1.0$. After engine start, sufficient fuel is burned off to provide the thrust margin required to break ground. Further burn-off during vertical rise will increase $T/W$ such that the thrust can be directed slightly off vertical. This will provide a horizontal thrust component to accelerate the airplane while the remainder of the thrust supports the aircraft. As the velocity increases, the wing lifting force will build up. The angle of attack variation will range from 90° to conventional angles of 0°–10°. The flight path is assumed level as soon as the aircraft leaves hover and starts the transition. Therefore, the angle of

attack must range from at least 80° to the low conventional values. The familiar interrelationships of the angle of attack and the velocity present a problem in this case. While the sources of data at this high angle of attack are limited, the trend of aerodynamic coefficients with angle of attack up to 90° may be shown from the classic experiments of reference 2. Actually unsteady force systems may be expected to exist throughout. The large drag coefficients act at the centroid of area of the wing when it is near the 90° condition. At angles from 60° to 90° appreciable lift coefficient and large drag coefficients act at nearly the same far aft position. From this point they result in extremely large trim moment requirements on the airplane if the velocity of flight is high. If stabilized flight conditions are to be maintained, the airplane must be able to trim these forces. Since the horizontal tail is at the same high angle of attack, its moment contribution with variation in deflection is insignificant, and this moment must be supplied by some auxiliary control source.

The airplane is troubled by the inherently unstable conditions which can exist when a reasonably high velocity is combined with these poststalled aerodynamic coefficients. The force patterns which develop are more apt to be dynamic and rapidly fluctuating than steady. These instabilities may lead to asymmetric stalling patterns or may set up conditions which place the airplane in regions of incipient spin. These regions where the airplane is in danger of incipient spin or rotary instability may be established by examining the criteria established by Glauert.[1] These criteria note that for rotary stability the sum of $dC_L/d\alpha + C_D$ must be positive. This limits rotary instability to regions of negative lift curve slope which exist after the angle for maximum lift has been exceeded.

By examining the points where this sum equals zero, it is possible to establish the angle above which the wing will diverge in a spin if disturbed initially. Examination of the poststalled lift and drag polars for the hypothetical aircraft with these spin criteria indicates possible regions of rotary instability. This condition, coupled with the unsteady force system which will prevail, causes inherent instabilities in the aerodynamic characteristics of the air frame. These factors make automatic stabilization of the airplane in this high angle of attack transition practically mandatory.

The build-up in moment which must be trimmed for the hypothetical airplane is significant. The force required becomes appreciably large while the airplane is at a high angle of attack where the effective control cannot be provided by deflecting an aerodynamic surface. The airplane must be trimmed with a down-tail force. It should be noted that these transition characteristics may also be considered representative of a steady wind condition which might exist at hovering. Since the aerodynamic controls are not capable of trimming the airplane at these high angles of attack, it will be necessary to provide the control force by some auxiliary system.

### Fixed Thrust Vertical Landing

The landing cycle for the fixed thrust airplane can be visualized in much the same fashion as the take-off. The pilot has two choices. He could assume a low angle of attack, and consequently increase stability, if he wished to follow a trajectory path—or a high angle of attack at high speeds, with consequent instabilities, if he wished to hold a level flight path. Since there are certain limitations advisable in the rate of vertical descent, it was felt that any large gain in altitude was detrimental to flight safety since it exposed the pilot to hovering flight at appreciable altitude for long periods of time. It was also extremely costly in fuel to operate near hovering thrust for the long time periods required to descend.

The other approach to a landing transition forces the aircraft to pass through the combination of high velocity with high angle of attack—but gives it the advantages of a low-altitude transition and a shorter time for descent. Automatic stabilization is desirable, and a source of large reaction controls is required. The airplane is relatively unstable without these appendages.

These considerations show a disturbing trend. They point out the possibility for increasingly severe aerodynamic instabilities in the transition region if a constant altitude transition is to be obtained for the fixed thrust airplane. These instabilities must be control-stabilized by using reaction forces in addition to the large trim forces which have been shown to be required. An obvious way to counteract these inherent instabilities is to depend upon a fully automatic stabilization system. The reliability of such a system then becomes the only margin of safety.

### Rotating Thrust VTOL

The other types of VTOL aircraft are basically the horizontal-attitude types. These hold the wing, tail, and fuselage in a conventional attitude while the thrust is rotated independently. The basic arrangement of the horizontal attitude types of aircraft may be represented by the air test vehicle (Fig. 1), which rotated complete engines, or the X-14 (Fig. 2), where the engine is fixed but a diversion system will rotate the thrust. This system allows the lifting wing and lifting thrust to be used either separately or together. This provides a flexible situation since the relative independence of these two functions can be utilized to follow a series of flight paths. The equations of motion important to the take-off and transition performance may be represented as follows:

$$T_x - W \sin \gamma - D = M(dv/dt) = (w/g)\ (dv/dt)$$
$$T_z + L - W \cos \gamma = Mv(d\gamma/dt) = (w/g)\ (d\gamma/dt)$$

### Rotating Thrust Take-Off

Using rotating thrust in conjunction with a horizontal attitude for the hypothetical 25,000-lb. aircraft, we can visualize a flight path similar to a conventional take-off and landing but elevated above the ground.

A schematic arrangement is shown in Fig. 4. The airplane can apply thrust and rise vertically at a moderate velocity of 5 ft. per sec. to an arbitrary hovering altitude. Rotating the thrust vector in small increments provides an acceleration forward where supporting thrust may be traded for a build-up in lift. The wing is held at an angle of attack below the stall angle during this transition. The airplane can take advantage of low thrust-to-weight conditions. The only high angle of attack encountered is the negative 90° angle of attack during vertical rise. Using a velocity of 5 ft. per sec. gives a negligible dynamic pressure of about 0.03 lb. per sq.ft.; so this condition does not produce strong aerodynamic influences.

The speed build-up transition is influenced slightly by drag forces, but gravity is not opposing the acceleration. A 10° angle of attack was chosen to avoid stall separation from the wing. The horizontal tail builds up control effectiveness as the airplane accelerates. Poststalled angle of attack is not combined with high level flight speeds. Under these circumstances, the wing lift, damping coefficients, and control effectiveness of the airplane build up with the square of the velocity. Since the airplane has sufficient control to trim for level flight, the build-up of aerodynamic moment can be trimmed throughout this flight region. The fixed angle of attack requires the same trim deflection angle as the $q$ increases as long as the pitching moment coefficients remain constant. At a velocity of about 15 ft. per sec. the wing Reynolds Number reaches 1,000,000, so it is safe to say that a normal relationship exists between the coefficient and the angle of attack. In the case of a 10° angle of attack, the airplane will be operating in the normal region of aircraft flight where the wing lift is attached, the drag coefficient is low, and the pitching moment coefficient is responsive to deflection of the horizontal control surfaces. It is possible to effect this transition in a level attitude at whatever altitude the pilot chooses to avoid obstacles. The thrust of the airplane is rotated intermittently, a few degrees at a time. Since the drag is low, speed builds up rapidly. For instance, a 10° angle of rotation on the thrust vector provides a cosine component lifting force of 24,600 lbs. and will also provide a sine component horizontal propelling force of 4,340 lbs. This well-known characteristic of the sine-cosine relationship comes close to providing both a maximum lifting vector and a maximum propelling force. As lift builds up with velocity, the thrust is rotated further, providing a larger accelerating force and consequently a greater speed. The velocity build-up takes about 20 sec. from hovering to level flight speeds. Variations in angle of attack, thrust rotation rate and timing, and altitude provide a large number of possible variations on this typical take-off flight path.

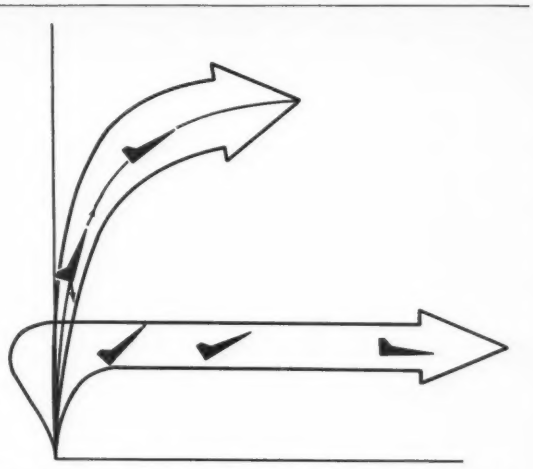

FIG. 4. Horizontal attitude VTOL take-off flight path

### ROTATING THRUST LANDING

The landing for the rotating thrust line airplane is also a low angle of attack maneuver. The thrust may be rotated while the airplane is in its approach to a landing at a speed above stall speed, with the wing supporting the airplane. Selecting the altitude for transition, the airplane can be flared to a level flight path with an angle of attack of 2° or 3°. The thrust may be rotated 10° forward of the vertical position and will thereby provide a decelerating force to slow the airplane. The thrust is increased to match the decay in wing lift as the level flight velocity decreases. The velocity decreases during the first 20 sec. to about half its value, and the angle of attack is brought up to 10° in this time. Thrust angle is held constant at the 10° forward of vertical position throughout the landing deceleration. Since vertical, in this instance, is defined with regard to the horizontal fuselage, the angle of attack acts to decelerate the aircraft further. Thrust is brought equal to weight in order to hover. A slight decrease permits descent at 5 ft. per sec. A thrust increase provides the flare-out for landing the aircraft with small impact.

The characteristics of both the landing and take-off transition regions are especially attractive. The instabilities which were discussed for the extremely high angle of attack are completely missing. The wing will act in a conventional range of angle of attack, reflecting lift and control effectiveness in direct proportion to flight speed. It is evident that the flight conditions become progressively better as the airplane proceeds from the hovering condition rather than deteriorating as in the previous case. There are no aerodynamic trim difficulties since the aileron, rudder, and elevator are all held in an angular relation with free-stream velocity which will permit a control build-up.

The transition reflects the action of a steady wind on hovering in this case, as well as the former. Wind effects on the hovering condition will not be adverse in this instance, however, since the airplane may be pointed into the wind so that the wing may experience the increased effectiveness which a steady wind gives to all conventional airplanes.

### Hovering Stability

The hovering characteristics of the vertical take-off airplane are radically different from the characteristics of the airplane in level flight. In the case of jet-propelled airplanes there are essentially no aerodynamic forces which affect the aircraft except those due to gust action or steady wind. Since these forces are related directly to the square of the velocity, they are a lower order of magnitude than the inertial and gyroscopic terms.

### Jet - Air-Frame Characteristic Equations

If the case is restricted to the jet aircraft since it is basically simpler, the equations of motion for the six degrees of freedom can be written.

All aerodynamic forces and moments are second-order terms which depend upon the products of two perturbation quantities. For this reason these terms may be neglected in a linear analysis of a jet VTOL hovering. The dominant terms in the analysis are those resulting from the gyroscopic effects of the engines. The comparative magnitudes of these gyroscopic terms and the damping terms in the equation may be examined using the hypothetical airplane as an example. Assuming a typical turbojet power plant, the resulting moment may be defined from a rate of 0.2 rad. per sec. in pitch and yaw. Since the horizontal-attitude VTOL airplane couples yaw and pitch when the engine is left horizontal, the gyroscopic pitching moment will develop from a yaw rate.

This gyroscopic pitching moment may be expressed as

$$M_G(\Delta\dot{\psi}) = J \cos \eta(\Delta\dot{\psi})$$

and the aerodynamic pitching damping moment as

$$M_A(\Delta\dot{\theta}) = -C_D 1/2\rho S_{HT} l_t^3 (\Delta\dot{\theta})^2$$

Using sea-level take-off conditions, an angular momentum of the engine equal to 30,000 slugs-sq.ft./sec., and a flat plate drag coefficient of 1.28 on the tail surface, the comparison shows that the aerodynamic moment is −25.8 ft.lbs., while the gyroscopic moment is 6,080 ft.lbs. With this difference in order of magnitude, it becomes reasonable to neglect the aerodynamic damping terms in the hovering condition.

The relationship between the angular momentum and inertial terms in the hovering case results in the development of a characteristic neutral oscillation of the airplane when it is disturbed. This neutral oscillation may be examined for the fixed stick condition for the air test vehicle, which was a very light airplane incorporating engines with high angular momentum. The period of this oscillation was about 2.7 sec. The period may be shown to depend principally on the square root of the product of the moments of inertia divided by the angular momentum of the engine. In the case of the air test vehicle where the engines were rotated, the period was related to the coupling of the pitch and roll axes:

$$T \backsimeq 2\pi\sqrt{(I_y I_z)/J^2}$$

In the case of a hypothetical airplane which would use a horizontal engine, such as the X-14, the pitch and yaw axes couple gyroscopically and the period is represented by

$$T \backsimeq 2\pi\sqrt{(I_y I_z)/J^2}$$

It is obvious that either an increase in the inertia of the airplane or a decrease in the angular momentum of the engine will increase this period. A pilot can manually control a neutral oscillation if the period is not too short. Based on the experimental success of the flight tests on the short-period air test vehicle and the X-14 airplanes, manual control of hovering was verified as a completely feasible operation.

It is important to note that the use of tip-mounted installations increases the inertias, while the use of a ducted propeller, developing a sizable thrust-to-horsepower, usually yields a reduced angular momentum. For this reason, the ducted propeller airplanes have extremely long periods and are generally easier to control than those with fuselage-mounted turbojet engines. The heavier jet airplanes, represented by the hypothetical airplane, would have longer periods than the Bell air test vehicle or the X-14 and therefore are easily controlled.

### Control System for Hovering

The selection of the control system for use on a turbojet-powered VTOL becomes a study of various methods of applying discrete forces since flow does not exist over the aerodynamic surfaces. It is necessary to consider the conventional pitch, roll, and yaw rotations, translation forward and sideward, and the additional translational control of the vertical plane. This vertical control is fundamentally tied to the source of power. The pilot must be able to adjust the net lifting force to permit hovering, slow vertical ascent or descent, and stabilization of disturbances. This control becomes intimately associated with the engine throttle. Thrust variation on a turbojet engine is steep at the conditions for take-off thrust. This indicates need for a vernier control on the throttle, permitting small variations in thrust in this steep gradient area of the engine. It is important that this variation be accomplished without superimposing control or trim changes about the other axes.

In considering the pitch, roll, and yaw controls, many systems could be devised. With the available jet from the engine, it is apparent that systems similar to those used in early rocket-powered missile systems could be used. Rotation of the engine thrust, which could be visualized as a vector passing through—but offset from—the center of gravity, could provide control about two axes. Large translational forces might be expected in conjunction with appreciable rotations. Operation on a large force requires extremely precise control of the force deflection. An additional force

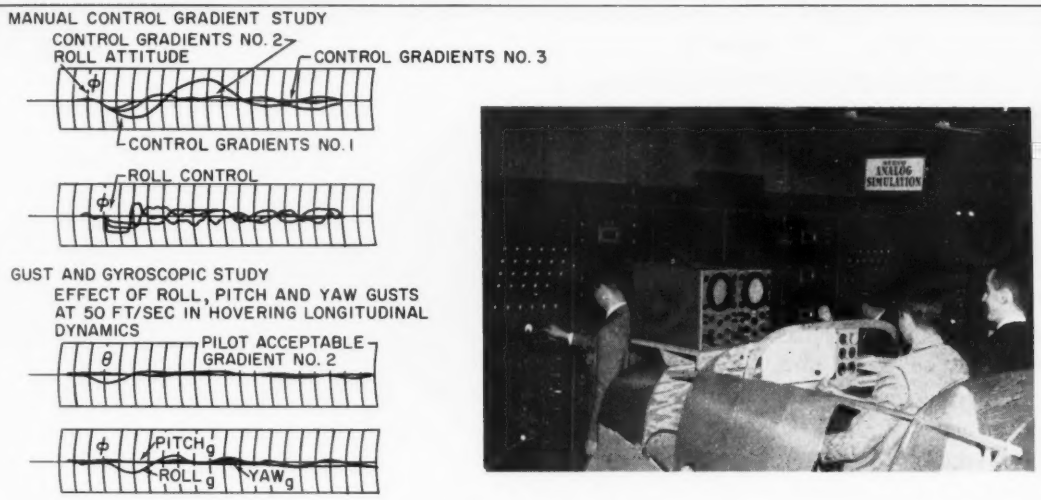


FIG. 5. VTOL hovering stability.

will be required for control about the third airplane axis. The use of the main jet thrust also requires coordination of the vertical translational degree of freedom since the amount of control used will couple directly with the lifting thrust.

It should be noted that the difficulties in utilization of the main thrust jet would be compounded if the jet itself were being rotated to provide an independence of vertical and horizontal thrust. Under these conditions, the yawing force would become a rolling force as the thrust was rotated from horizontal to vertical. At all intermediate points an intermixing of control around both axes would exist which would require unscrambling to provide the pilot with correct sense of control. This complication of control implies automatic control requirements.

Another approach to the control problem appears possible using small forces on long moment arms. This approach is also attractive since analysis indicated that at least two forces, nonlinear with the c.g., would be necessary in order to develop control about the three rotational degrees of freedom. Small forces can be adequately controlled manually and would provide close control of the change in moment. Because of their low order of magnitude, translational coupling can be essentially eliminated from the rotational control, yielding pure pitch, roll, and yaw moments. The use of three or four forces, any two of which are nonlinear with the c.g., are also workable systems. This arrangement of control forces can be suited to locations on the extremities of the airplane. The tail and wing tips and the location of the ailerons, rudder, and elevator are ideal since they provide the maximum moment arms together with built-in actuating systems provided for the level flight controls.

### Auxiliary Reaction Controls

The use of this latter system requires a scheme for generation of reaction forces. Methods which are obvious for airplanes containing a jet-engine installation may be considered as turbine exhaust bleed, engine compressor bleed and subsequent burning at the control point, or compressor bleed for a nonburning system. Other solutions involve the use of separate rocket-powered systems which require the tankage and lines necessary to operate discrete rocket nozzles at the control points.

### Stability of Pilot - Control System - Airplane Combination

The other element beyond the air frame and the control system is the pilot. He provides the vital link in this stability picture. The evaluation of manual control capability was easy to obtain by using a set of controls in conjunction with two Reeves electronic analog computers. The necessary gradient and control levels required by the pilot were determined by using an analog set up as shown in Fig. 5. These studies yielded traces similar to those shown. The study was conducted using a visual presentation on oscilloscopes which permitted the pilot to stabilize the aircraft manually by using the aircraft controls in the simulated cockpit. The pilot was able to do this job successfully if the control gradient and force level were raised to a satisfactory level.

### Transition Flight

As the airplane is accelerated from hovering to level flight speeds, the aerodynamic forces become increasingly important until they dominate the flight regime. The two types of jet aircraft have been discussed with regard to the aerodynamic coefficients which will be encountered. From this discussion it is evident that certain instabilities may be expected in the fixed thrust versions while the horizontal attitude VTOL will move progressively into a better condition of stability in passing through transition. The damping forces will

build up on wing and tail surfaces as the square of the velocity. The use of the low angle of attack provides an increasing build-up of aerodynamic control on the conventional surfaces with no tendency for divergence of the air frame - pilot - control system combination.

### Level Flight Condition

The level flight of a VTOL airplane can be considered quite similar to present-day aircraft if the overall configuration is reasonably conventional. In all cases, however, the VTOL airplane has a high level of thrust available. Because of this thrust level, the airplanes can be expected to have a high angular momentum component from the turbojet engines. This gyroscopic effect provided an interesting influence in the case of the Bell air test vehicle.

The gyroscopic effect superimposed the heavy pitch damping effects of the horizontal tail on the lateral directional short-period oscillation. This was a mutual interchange in that the pitching oscillation became less heavily damped. The effect is appreciable and in the right direction to help damp the dutch roll oscillation due to the reasonably large horizontal tail used on this airplane. It should be noted, however, that, if both the longitudinal and lateral directional characteristics are lightly damped, this effect could be adverse as it would couple all three axes as a combination of gyroscopic and aerodynamic coupling.

### Conclusions

As a result of these studies of the VTOL take-off and transition flight regimes, it can be concluded that:

(1) Low angle of attack transition permits manual stabilization and aerodynamic trim.

(2) Inertial and gyroscopic terms dominate jet hovering.

(3) Small control forces minimize coupling and precision requirements.

(4) High angle of attack transition requires automatic stabilization and large reaction trim forces.

(5) Wind conditions are favorable for rotating thrust type of VTOL.

(6) Gyroscope coupling from the high level of thrust influences level flight stability.

### References

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[2] Knight, M., and Wenzinger, C. J., *Wind Tunnel Tests on a Series of Wing Models Through a Large Angle of Attack Range Part I—Force Tests*, NACA Report 317.

[3] Critzos, C. C., Heyson, H. H., and Boswinkle, R. W., Jr., *Aerodynamic Characteristics of NACA 0012 Airfoil Section at Angles of Attack From 0° to 180°*, NACA TN 3361, January, 1955.

[4] O'Malley, J. A., Zabinsky, J. M., Roehrs, F., Isom, J., and Landphair, L. C., *Aerodynamics of the Bell VTOL Air Test Vehicle*, Bell Aircraft Corporation, October, 1953.

[5] O'Malley, J. A., *An Application of the Ducted Propeller to a VTOL Transport Airplane*, Aeronautical Engineering Review, Vol. 15, No. 8, pp. 52–55, August, 1956.

[6] Woods, R. J., *Convertiplanes and Other VTOL Aircraft*, Preprint 738, Society of Automotive Engineers, April, 1956.

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## System Considerations in Instrument Dynamics (Continued from page 72)

will be error. The resulting response measurement is the only one with validity.

In the case of pressure measurements, the remedy is to make the tubing small in order to obtain small volume and make it large to obtain smaller orifice effects. Implicit in this contradiction is an optimum tubing diameter which is rarely even calculated. Length is such an important factor that reason can hardly be found for the 40 or so feet of tubing often found even in fighters. The modern air data computer and the electrical, servoed force balance altimeter have sensors that can be located remotely, often in the wing at the root of the pitot tube. If stand-by instrumentation requires the pressure line anyway, separate or constricted lines assure that the stand-by equipment does not deteriorate the accuracy of the more precise electrical sensors.

It should be noted that precision altimetry and measurement of Mach Number require correction of the static pressure for static pressure defect—i.e., for effects of Mach Number, angle of attack, and sideslip. Angle of attack readings require correction for Mach Number. The writer has never seen any evidence that any site or location of sensors can eliminate these corrections. The somewhat increased correction in going to a shorter static line, or even to static ports, often results in a lower overall error. No site for vane or tube will eliminate the corrections. "Siting" the sensors should be done to minimize total error—static and dynamic.

All the magnificent construction and highly developed feedback theory of the instrument maker is of minor use because, by specification, his responsibility ends at the edge of the problem. But somewhere there is a man whose duties are delineated by the word "systems." There exists for him the responsibility and certainly, with consideration of some often-ignored facts, the capability for the problem's solution.

What then are the roles of the Navy? They are these: first, to provide military, economic, and political links across the seas for the nations of the free world and to deny corresponding linkage to the nations of the Communist bloc; and, second, to use the ocean areas as a springboard for offensive operations and as a vast maneuver area for the defense in depth of ourselves and our allies.

In cold war what is needed may be a show of force, as in the Jordan troubles. Ships may come and go on the international waters of the world without treaty or passport, without question of sovereignty or jurisdiction. Our Navy and its ships are our finest ambassadors. They are the strong arm of restraint—guarding our nationals in the Suez crisis or our friends in the Tachens, hoisting the flag of warning over Formosa—a big brother bolstering a faltering ally or a policeman on the beat subduing an irresponsible international brigand.

Our Navy is often able to suppress trouble before it starts merely by being present and available. Herein the advantage of being on the scene, as our present Sixth and Seventh Fleets are in the Mediterranean and the Far East. Being present or being able quickly to reach an area of tension gives us an immense opportunity for preserving peace, discouraging aggression, and forestalling trouble.

Our naval task forces are tailored to classic military principles of mobility, concentration of power, and economy of force. Precisely because of our ability to develop and use the new weapons systems, the Navy is a force of economy—which makes its future certain.

Naval power gives us the power of choice. Naval power has the capability of precision delivery of measured force. Our Government needs a choice of action—it needs alternatives—when confronted with a dangerous international situation.

In unlimited war, we would have important special capabilities: carrier-based air attack against objectives which threaten our control of the seas, seaplanes based on mobile supporting ships, and surface and submarine-launched guided missiles. Because these attack systems are based on the sea, they can concentrate on the greatest threat or disperse to the farthest oceans. They are relatively free from the threat of missile counterattack. They are secure from the political tangles of foreign bases. They do not threaten, they are not provocative, but they are available. Most important of all, they can force the enemy to divert his fire away from our homeland.

One of the most obvious features of our national policy today is our emphasis on collective security. The basic strategy of the Communists is to divide and conquer, to isolate North America and the United States. The mainstay of our collective security system is our mutual love of freedom and our respect for the dignity of man. Its cement is sea power. . . . In reality, no one of our allies can be supported without sea power.

You are entitled to ask, "What is the future of Naval aviation?" We answer, "It is bright." At the nation's need, we see Naval aircraft hunting submarines, striking the sources of enemy Naval power, guarding our ships and our sea flanks against air attack. We see Marine landing forces employing helicopters in vertical envelopment objectives and Marine and Naval aircraft supporting the Marine divisions ashore. We see sea-based air controlling the seas as it has since the airplane came of age.

To realize all this, we must reduce, drastically, the costs of hardware and of operations. Dollars, of course, are not everything. But in peacetime and in wartime, they are the best measure of manpower, material, and effort that we have ever been able to devise. So, clearly, what we want is military worth—the greatest military value for the money. Where the military worth is high, we will buy. Where it is not, we won't. It is as simple as that.

And what is military value in weapons? It is that combination of careful, ingenious design, advanced technology, and down-to-earth common sense which yields the simplest, lightest, most reliable weapon to do the job—and not one thing more.

Many people ask our view nowadays on the relationship of missiles and unarmed aircraft. Will the missiles supplant the aircraft in military applications? I think the answer is simple: It will supplant the aircraft where it can do the job better, and it will never replace it where it cannot.

In air defense and in nuclear attack it probably will, some day. In reconnaissance, logistics, and in the numberless applications of sea-air power to limited conventional war and politico-military operations, it probably will not. So here again we need a well-balanced team in which each component does that for which it is best fitted.

The American aircraft industry has done well for Naval aviation. It has produced, consistently, aircraft that have held, and that now hold, world records in speed and range for military aircraft. They yield nothing in effectiveness to aircraft of any service of any power. We have many dramatic and recent examples. With the steam catapults, angle decks, mirror landing systems, and other improvements of modern carriers we have broken the shackles of carrier aircraft design. With the new hydrodynamics we will break the shackles of seaplane design. By taking advantage of the capabilities of sea bases, we will develop offensive and defensive missiles of higher military worth than can be developed in any other way. It has been a job well done.

But now industry must do all this and much more—it must do it at absolute rock-bottom cost. Let me speak plainly—the producer who reduces his costs is the one who will survive. To the sound barrier, the heat barrier, the energy barrier, we add one more—the cost barrier. I have the utmost confidence that the energy and creative imagination which overcame the others will overcome this one too.

## Corporate Member News *(Continued from page 33)*

• **American Steel & Wire Division, United States Steel Corporation,** has announced the appointment of George A. Pyle as Assistant Manager, Stainless Steel Products Sales.

• **Bendix Aviation Corporation** has announced that it will manufacture a long-range navigation system called Dectra to provide "electronic sky tracks" to ease the squeeze on transatlantic air lanes. Manufacture and sales rights to the system have been obtained by the Pacific Division. Dectra is said to operate over a range of 2,300 miles and to provide a pilot with aircraft position within 3 miles of geographical position when in the middle of the Atlantic. Dectra is now in operation between Newfoundland and Scotland. . . . The firm's Computer Division has announced an expansion program to double the size of its manufacturing facilities. . . . Montrose Division has announced the appointment of Herbert J. Pyle as Assistant Sales Manager.

• **Boeing Airplane Company** reports its 717 jet air liner will be offered to air lines for delivery in 1960. The short-to-medium range jet is said to operate economically on flights of from 200 to 1,700 miles, with cruising speeds of from 550 to 600 m.p.h., and at altitudes of from 25,000 to 40,000 ft. . . . Initial testing of a new $2 million supersonic wind tunnel with speed range from Mach 1 to Mach 4 has been conducted by the manufacturer, the firm announced.

• **Douglas Aircraft Company, Inc.,** has announced plans to study human reactions to the sound from the engines of jet aircraft in flight. Purpose of these psychoacoustical tests, to take place at the firm's new sound lab at Santa Monica Division, is to establish an "acoustical comfort index" for jet transport travel. . . . T. E. Springer, El Segundo Division Vice-President and General Manager, has retired. Harold G. Hynd, formerly Vice-President and General Manager, Tulsa Division, has been appointed to succeed Mr. Springer. Jess L. Jones succeeds Mr. Hynd. . . . Santa Monica Division reports that 16 aircraft, valued at $31 million, were delivered to ten different air lines during June. The firm also reports receipt of an order for two DC-8's from Olympic Airways of Greece.

• **Eastern Air Lines, Inc.,** has announced daily one-stop flights from New York, N.Y., to Mexico City and return. A 1-hour and 15-min. route stop has been scheduled at New Orleans, La. The new first-class flight will connect with other first-class flights from Boston, Mass.; Newark, N.J.; and Atlanta, Ga.

• **Fairchild Engine and Airplane Corporation,** Fairchild Engine Division, has announced completion of its new aerodynamic and thermodynamic research facility. . . . The firm also announced receipt of an order for five F-27's from the Venezuelan air line Avensa. . . . The Stratos Division has appointed W. Thomas Stark to the new post of General Sales Manager, Aviation Products.

• **The Garrett Corporation's** AiResearch Aviation Service Division reports that it is installing a gas-turbine unit in a CAA Convair 440 to provide power to flight check radio navigational and communications facilities throughout the nation. The division also has been awarded an exclusive franchise to provide fueling services at Los Angeles International Airport for all aircraft except those of air lines which have their own facilities. The division's Maximizer Kit, designed to provide an additional 20 m.p.h. on DC-3's, will be demonstrated in 14 states across the nation, District of Columbia, Toronto, Montreal, and Ottawa.

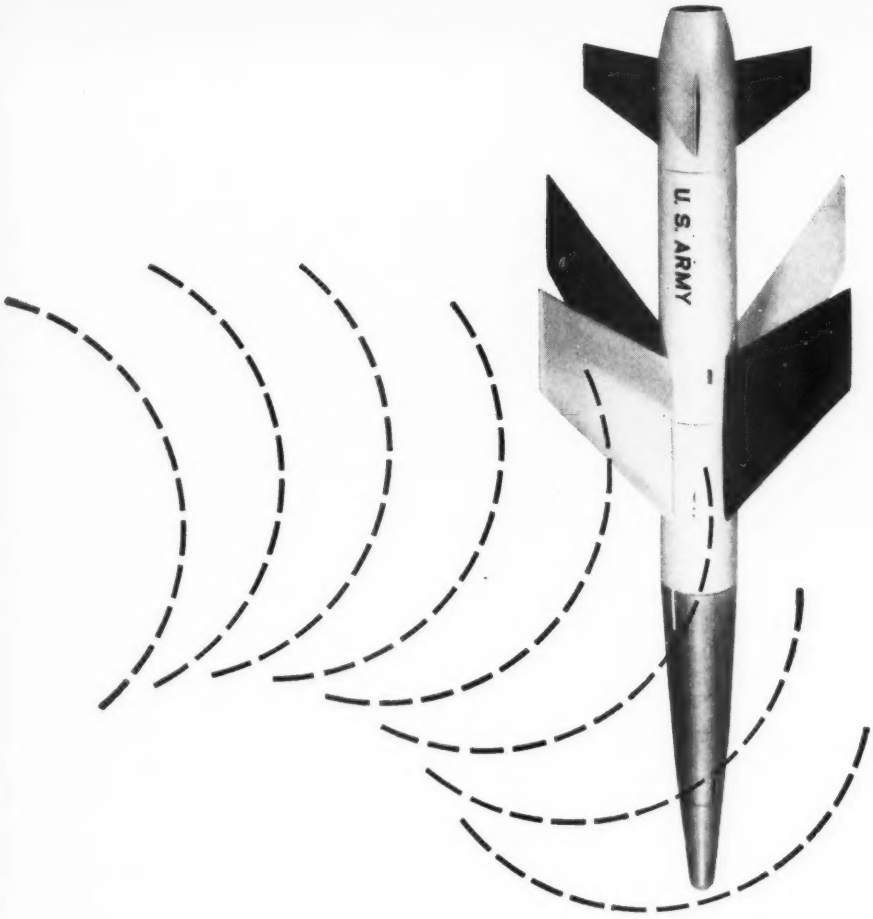
• **General Dynamics Corporation. . .** Convair Division and the Air Force have announced that new and different types of electronic (automatic) control systems are being used (1) to guide the B-58 Hustler to and from its target and (2) for releasing pods. . . . Convair-Astronautics reports it has begun to occupy its new $40 million Atlas ICBM plant northeast of San Diego, Calif. . . . Convair's European sales office in Geneva will be expanded, the division announced, and will be managed by George C. Prill who has been Assistant Manager of Commercial Sales, San Diego. . . . Convair-Astronautics has named Willard D. Walker Chief Electronics Engineer.

• **General Electric Company** engineers have developed a closed-circuit three-dimensional color television system for remote servicing of reactors used in development of a nuclear aircraft propulsion system. The firm says the color stereo system was developed to permit use of color-coded parts in reactor components and to provide the degree of precise depth perception required for their correct positioning. . . . Electronic Components Division sales offices are scheduled for a move from Schenectady, N.Y., to division headquarters at Owensboro, Ky., to expand service to electronic parts wholesalers, according to the firm. The division also has announced an addition to its line of semiconductor rectifiers—a series of 170°C. silicon rectifier stacks—in production at the Semiconductor Products Department. The division's Receiving Tube Department has announced the appointment of Paul S. Coomes as District Commercial Engineer, and Sylvester W. Wylie as District Sales Manager. . . . Apparatus Sales Division reports installation of blanket floodlighting (mercury quartz vapor lamps and floodlights) at New York International Airport's new Terminal City nearing completion. . . . Chemical & Metallurgical Division has announced the appointment of Reuben Gutoff as Manager, Resin and Fluids Operations, Manufacturing Section, Silicone Products Department.

• **General Precision Equipment Corporation. . .** Kearfott Company, Inc., division has announced production of a miniature transistorized servoamplifier, Type T3103, said to be small, lightweight, rugged, and capable of delivering 6 watts maximum power. Kearfott also has announced the availability of high-purity aluminum oxide ceramics for use in radomes, wave guide components, vacuum tube envelopes, and for applications where high resistance to radiation is required. . . . General Precision Laboratory Incorporated has announced promotion of Raymond L. Garman from Executive Vice-President to the new post of Chairman of the Board, and James W. Murray from Executive Vice-President to President and Chief Executive Officer.

• **G. M. Giannini & Co., Inc.,** engineers have developed a highly sensitive variable resistance temperature probe with a range of from −350° to +800°F., the firm announced. Model 49132 Immersion Probes are designed to resist abrasion and environmental stresses in air or fluids, are AN threaded for insertion into tapped holes, and are said to withstand pressures higher than 3,000 psi. . . Giannini also has announced a new potentiometer-output pressure transducer said to combine the ultimate in compact case design with light weight and high performance. The Model 451218 measures 1 in. on a side and is said to have a high level voltage output (to 50 volts) that in most cases can be used

**Latest version of the Chance Vought Crusader, the F8U-1P photoreconnaissance aircraft, set a new official record from Los Angeles to New York of 3 hours, 23 min., and 8.4 sec. Marine Major John Glenn, Jr., piloted the plane shown, averaging 725.55 m.p.h. over the 2,456-mile route. Cameras (below the insignia) photographed the nation from coast to coast during the flight. Area-rule design can be seen behind the cockpit.**




**NEW WEAPON, NEW CONCEPT**

An important new weapon for a new U. S. Army concept is now being delivered in quantity by Martin-Orlando. This is LACROSSE, a field artillery guided missile, developed to implement the combat concept of the Pentomic Army...a "fighting" Army consisting of self-sufficient highly mobile battle groups. LACROSSE will provide these battle groups with the shockpower of extraordinary speed, mobility and accuracy in heavy armament support of their operations. LACROSSE is the first generation of an entirely new kind of general purpose weapon. All of its components, consisting of the missile mounted on a standard Army truck and a guidance system, can be airlifted to advance areas. The missile is fired in the general direction of the target—without target data at the launching site. Its pinpoint accuracy is controlled by a forward observer. The Martin Company, with more than 10 years of design, production and operational experience in guided missiles, today stands as a leader in this important field.

**MARTIN**

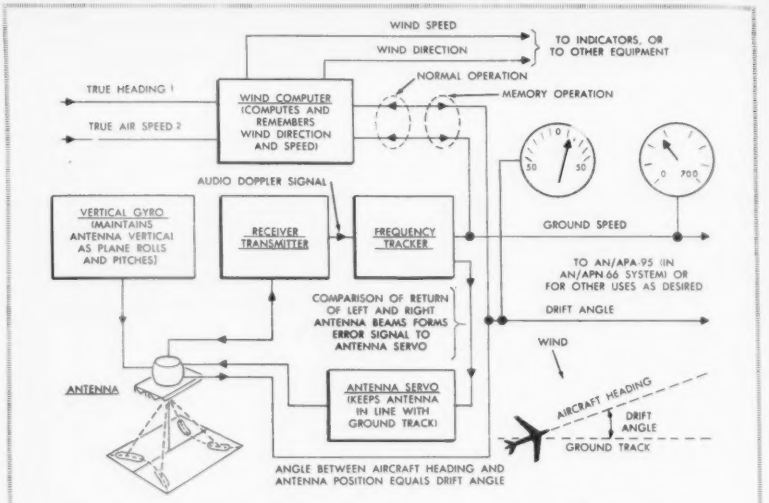
BALTIMORE DENVER ORLANDO

directly without amplification. . . . The firm has published a new *Airborne Components* catalog with information on Giannini's full line of transducers. The catalog also contains a technical data section with previously unpublished data on the instruments.

• **The B. F. Goodrich Company,** Aviation Products Division, has developed a new man-made rubber compound said to withstand both subzero cold and temperatures higher than its own vulcanizing point. First use of the new compound has been in a lightweight, flexible membrane part of the fueling system for Boeing Airplane Company's Bomarc missile. The division also announced the appointment of Donald C. May as Section Manager, New Products Development. . . . John N. Hart, Director of Employee Relations, has been promoted to Controller of the company.

• **The Goodyear Tire & Rubber Company, Inc.,** has announced that it is supplying fuselage fuel cells for the Boeing KC-135 tanker and that its subsidiary Goodyear Aircraft Corporation is producing the plane's pilot directional doors, plastic fin tips, and Doppler doors.

• **Lear, Incorporated,** Grand Rapids Division, has announced it will assemble component parts of the Bomarc missile's electronic "brain" under glass in a special room within a room designed for closer control of dirt and lint levels. The division also has announced development of an automatic-disconnect switch which is magnetically held and automatically disarmed when the energizing voltage drops between 13 and 5 volts. Switches are available in single-pole and double-pole models in corrosion-resistant casings. A new pneumatic power unit said to operate in temperatures far above the tolerance range of known hydraulic or electrical systems also has been announced. The device reportedly develops exceptionally high torque at relatively low speeds, does not disintegrate under overspeed conditions, and offers a reliable, fast-response power source for thrust-reversers, accessory drives, actuation of air inlet and nozzle-positioning systems, and reactor-rod positioning. . . . LearCal Division has announced a lightweight Glide Slope Receiver containing a fully transistorized internal power supply with no moving parts (Model LGSR-1). . . . Lear-Romec Division is manufacturing what is said to be one of the smallest lightweight fuel pumps, Model RG16140, consisting of a positive displacement rotary vane pump, an explosionproof electric motor, and a radio noise filter. Internal wiring to an AN-3102A-10SL-4P electrical connector provides for reversing the direction of rotation through external switch connections.


WIND SPEED
WIND DIRECTION
TO INDICATORS, OR TO OTHER EQUIPMENT
NORMAL OPERATION
MEMORY OPERATION
TRUE HEADING 1
TRUE AIR SPEED 2
WIND COMPUTER (COMPUTES AND REMEMBERS WIND DIRECTION AND SPEED)
AUDIO DOPPLER SIGNAL
VERTICAL GYRO (MAINTAINS ANTENNA VERTICAL AS PLANE ROLLS AND PITCHES)
RECEIVER TRANSMITTER
FREQUENCY TRACKER
GROUND SPEED
TO AN/APA-95 (IN AN/APN-66 SYSTEM) OR FOR OTHER USES AS DESIRED
COMPARISON OF RETURN OF LEFT AND RIGHT ANTENNA BEAMS FORMS ERROR SIGNAL TO ANTENNA SERVO
DRIFT ANGLE
WIND
ANTENNA
ANTENNA SERVO (KEEPS ANTENNA IN LINE WITH GROUND TRACK)
AIRCRAFT HEADING
DRIFT ANGLE
GROUND TRACK
ANGLE BETWEEN AIRCRAFT HEADING AND ANTENNA POSITION EQUALS DRIFT ANGLE

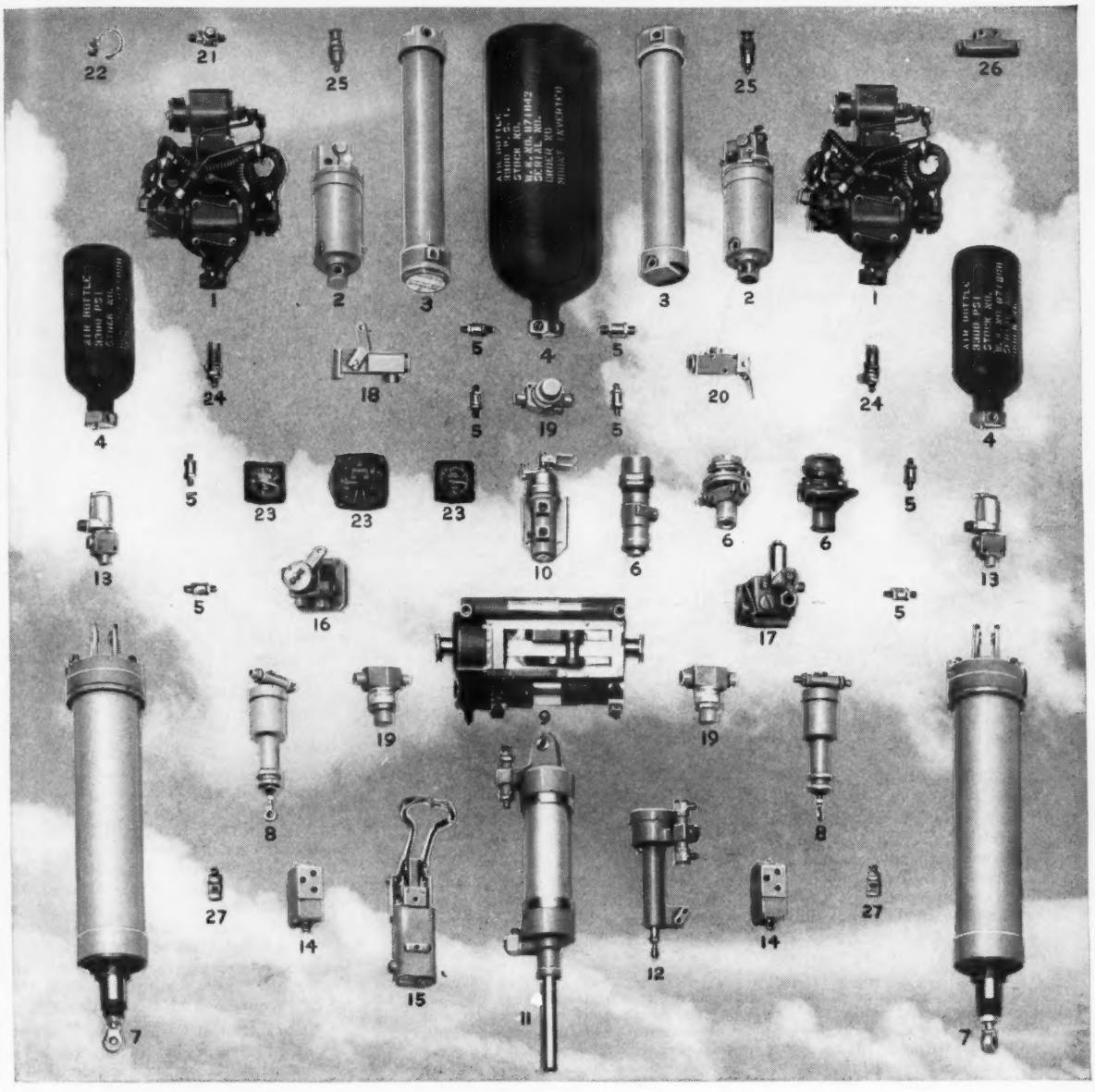
**This Figure from General Precision Equipment Corp., General Precision Laboratory Inc., shows how the firm's Doppler navigation instruments work. Pictured is a basic functional of AN/APN-81, or AN/APN-66 "Front End." The AN/APN-81 measures ground speed and drift angle and also computes wind speed and direction. Wind information is "remembered," and ground speed and drift angle automatically computed in case of a signal loss. Ground speed and drift angle are changed automatically when the aircraft maneuvers or changes speed during the memory period.**

• **Lockheed Aircraft Corporation. . .** Missile Systems Division reports that a minute sun position indicator in one of the firm's X-17 missiles was still functioning after hitting the ground with impact forces estimated at 1,000g. The instrument was recovered from under 12 ft. of sand, the report said. The division also has announced that construction has begun on a fourth 51,000 sq.ft. laboratory at its Palo Alto research and development facility. Stephen J. Jatras has been appointed to the newly created position of Assistant to the Director of the Research and Development Branch. . . . Georgia Division reports the C-130 Hercules has taken off in 150 yards with JATO bottles used as boosters. The firm's new jet utility transport was assigned to the division for sales and production. In addition, a market for a commercial version of the Hercules is being investigated. S. M. White has been appointed Master Scheduling Manager and E. J. Schon, Chief Planning Engineer, the division has announced. . . . Electra Notes: Nose section has been joined to the main fuselage. The Allison 501 turboprop engine was successfully tested in an artificial sandstorm, "swallowing" 253 lbs. of dust. Hydraulic research specialists have completed a mockup of the transport's hydraulic system for test purposes.

• **Manning, Maxwell & Moore, Inc.,** Aircraft Products Division, is manufacturing a Type 141LA1 gross thrust measuring system, said to be entirely pneumatic in operation and drawing its power from compressor discharge pressure. Two components, one engine and one cockpit mounted, weigh only 1.5 lbs. complete, according to the company.

• **The Martin Company's** Missile Master electronic system for controlling and co-

**Radioplane Co., a subsidiary of Northrop Aircraft, Inc., shows its new Air Force XQ-4 supersonic target drone mounted on the wing of a B-50 launch aircraft. Designed to exceed performance characteristics of all currently operational drones, the XQ-4 is undergoing flight tests at Holloman AFB. The turbojet-powered drone is said to have a ceiling in excess of 60,000 ft., is about 35 ft. long., has a 12-ft. wing span, and is recoverable through use of a three-stage parachute. It is radar controlled.**



**Here it is** — all the hardware needed for an all-pneumatic aircraft. All the items shown are pneumatic system components on the new Fairchild F-27, and open the door to an exciting new era of aviation. Similar pneumatic equipment is now available from Kidde on an off-the-shelf basis, and modifications to your own specifications or design requirements are available through Kidde's vast creative engineering department.
Let Kidde engineers show you how faster-operating, lighter-weight pneumatic systems can better solve your power problems!

1. Compressor
2. Moisture separator
3. Chemical dryer
4. Air bottle
5. Check valve
6. Pressure reducer
*7. Actuator, main gear
*8. Actuator, up lock main gear
9. Actuator, nose wheel steering
10. Valve, servo, nose steering
11. Actuator, nose gear
12. Actuator, up lock nose gear
13. Valve, propeller brake
14. Valve, wheel brake
15. Valve, emergency brake
16. Valve, emergency landing gear
17. Valve, solenoid, landing gear
18. Valve, manual, isolation
19. Filter
20. Valve isolation
21. Pressure relief
22. Valve, ground charging
23. Pressure gauges
24. Valve, relief
25. Valve, back pressure
26. Shuttle valve
27. Valve, rapid exhaust

*Items 7 & 8 designed in cooperation with and furnished by Stratos Division of Fairchild.*

**Kidde**

**Walter Kidde & Company, Inc., *Aviation Division***
**1011 Main Street, Belleville 9, N. J.**

**District Sales Engineering Offices:** Dallas, Tex.—Dayton, Ohio—St. Louis, Mo.—Seattle, Wash.—Van Nuys, Calif.—Washington, D. C.

Walter Kidde-Pacific, Van Nuys, California • Walter Kidde & Company of Canada Ltd., Montreal

ordinating fire of Nike antiaircraft batteries also will coordinate the new Hawk low-altitude air defense missile, according to a joint announcement by the firm and the U.S. Army.

• **Minneapolis-Honeywell Regulator Company,** Aeronautical Division, has announced formation of a contract repairs program for maintenance of aircraft and missile electronic equipment. Heading it is George P. Smith, division Chief of Field Service.

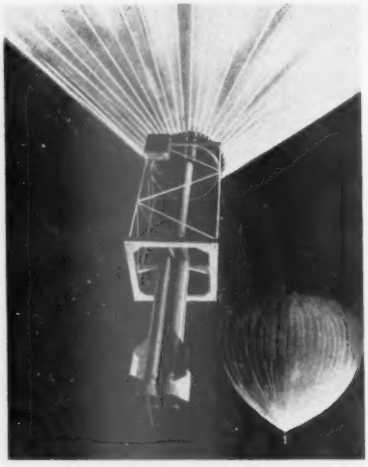
• **Norden-Ketay Corporation** has announced a licensing agreement with Société Anonyme Presilec of Paris for the manufacture and sale of the firm's synchro and servomechanisms in France. . . . Metro P. Sirko has been appointed to the new post of Eastern Regional Sales Manager.

• **North American Aviation, Inc.,** Atomics International Division, has announced it will build a 50-kw. nuclear research reactor in Milan, Italy, at the Enrico Fermi Nuclear Study Center of the Politecnico of Milan.

• **Pan American World Airways, Inc.,** celebrated the twentieth anniversary of its first transatlantic survey flight on July 5. The air line also announced all-cargo service between San Francisco, Calif., and Honolulu, to operate once a week.

• **Pesco Products Division,** Borg-Warner Corporation, has established nationwide distribution of parts and replacement units for factory-authorized and CAA-approved overhaul, through seven leading aviation distributors. Richard A. Powley has been appointed President of the division.

• **The Ramo-Wooldridge Corporation** held its Second Annual Summer Panel Meeting in Los Angeles, Calif., July 15–26, to study current advances in missile art, their effect on future weapon systems, and how this knowledge may be applied to further exploration and investigation of the universe.



**Five Thiokol Chemical Co. Recruit rocket engines will be launched from a balloon from 100,000 ft. in the Air Force Project Far Side, according to the firm. The 200-ft. diameter balloon will carry the solid propellant rockets to that height before the rockets are fired. A 6- by 4-in. instrument package will be carried for investigating physical phenomena at extremely high altitudes. During the ascent and descent a miniature radio transmitter will transmit measurements of cosmic rays and other data to ground receiving and recording stations.**

• **Reaction Motors, Inc.,** has announced the creation of a separate Applications Engineering Department for Solid Propellant Rocket Power Plants. William M. Davidson heads the new department, which is responsible for the development of new business in the field of solid propellants.

• **Republic Aviation Corporation** has announced completion of extensive testing of a new low-cost aerial refueling system which the firm says can turn fighters into tankers and back again in a matter of minutes. Republic's F-105 had its first public showing during an Air Force 50th Anniversary July 28 at Andrews AFB. The firm also announced the appointment of Brig. Gen. C. Pratt Brown USAF (Ret.), as Assistant to the President for Special Assignments.

• **Ryan Aeronautical Company** has opened a new Engineering and Research Center said to have the most modern facilities for ground-testing components of high-speed aircraft and missiles, at the firm's Lindbergh Field plant, San Diego, Calif. Ryan also announced that it has completed the first jet air liner aft fuselage section ever built in this area—a 3-ton section, 40 ft. long, containing 36 windows. Bruce Smith, Vice-President—Engineering and Military Relations, has reported three of President Eisenhower's military advisers have been given a complete briefing on the Ryan X-13.

• **Solar Aircraft Company** has announced that a 500-hp. Solar Jupiter gas-turbine engine is being used on the U.S.S. "Gyatt," first guided-missile destroyer, to furnish emergency shipboard and missile-launching power.

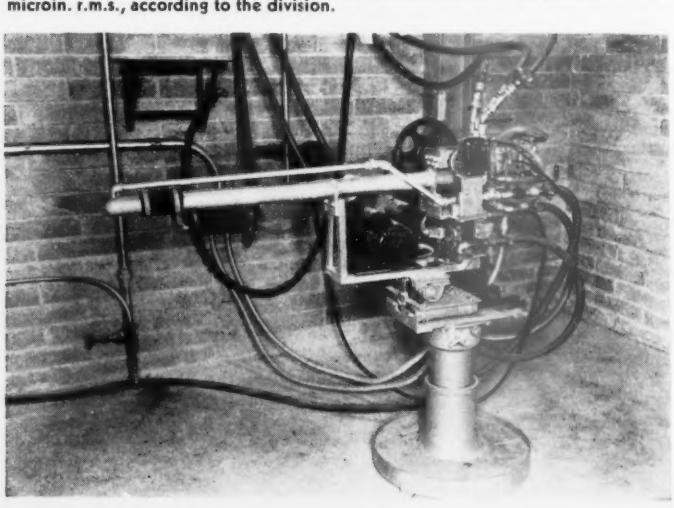
• **Union Carbide Corporation,** Linde Company division, has developed a new welding method for joining spaced metal sheets with thicknesses up to 1/8 in. and gaps or spaces up to twice the thickness of the bottom sheet. In the new method, Linde engineers report that a delayed wire feed is used with standard Sigma spot-welding equipment and argon shielding gas so that the arc melts a hole through the top sheet and fuses the molten material to the lower sheet. Then a column of metal is built up until it fills the hole and fuses with the top sheet. The division also has announced that it has fabricated large-sized, industrial sapphire clear crystal discs, 5 in. in diameter. . . .Complete information on using molecular sieves as a superior drying agent for gases is given in a new brochure, *Dry Gas? Use Linde Molecular Sieves,* available from the division.

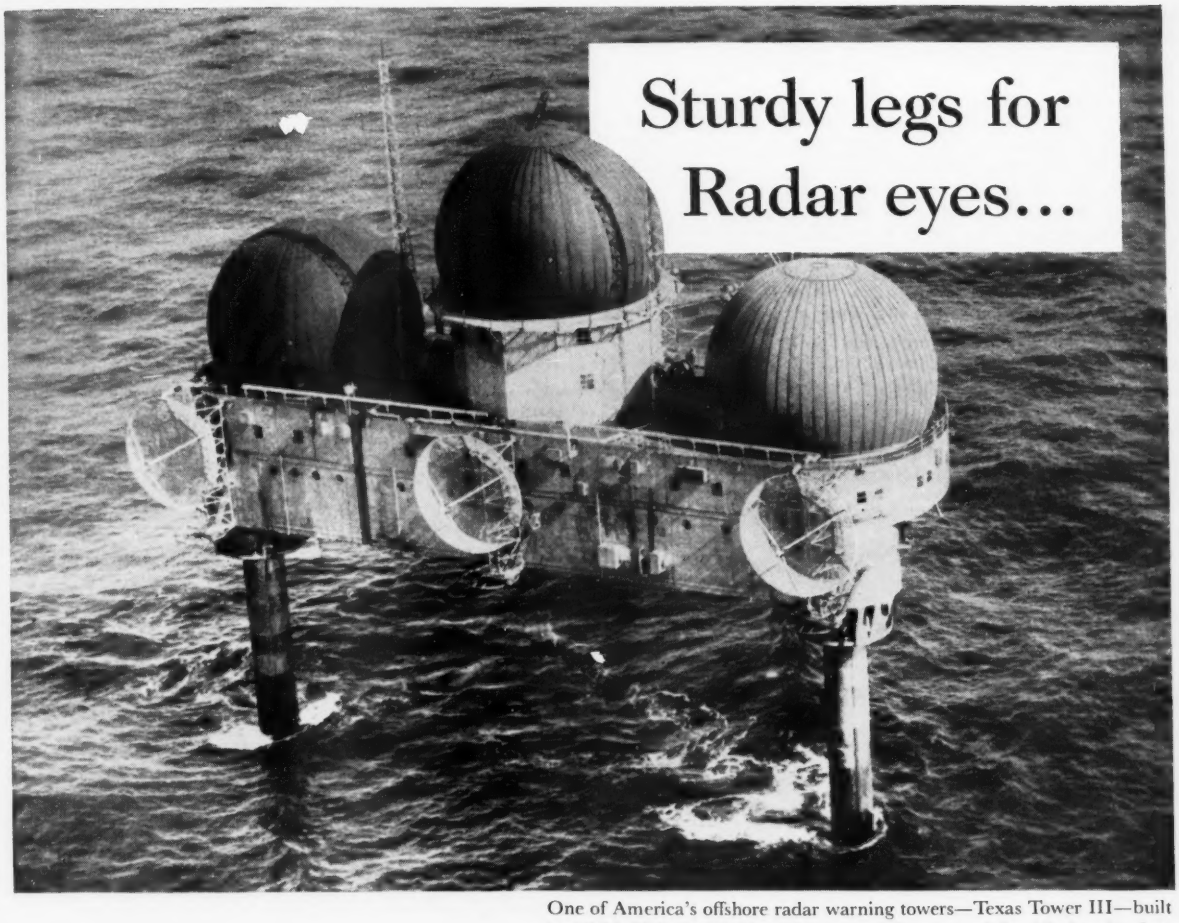
• **United Aircraft Corporation,** Hamilton Standard Division, has announced that it is producing a compact air-conditioning system for the Lockheed F-104A Starfighter, which cools and pressurizes the cabin and electronic compartment of the aircraft.

• **Vertol Aircraft Corporation** has announced the appointment of Felix A. Kalinski to the new position of Assistant to the President, in charge of long-range planning. Vertol reports that the Air Force has landed its H-21 helicopter on ice island T-3 in the Arctic Ocean, said to be the first ice-landing for a helicopter. Also, nine H-21's were turned over to Spartan Air Services Ltd. of Ottawa for transport duties on the Mid-Canada Early Warning radar line, according to the firm.

• **Vickers Incorporated** has announced quantity production of a new oil-cooled motorpump for turbine-powered air transports, designed for continuous-duty applications with a weight said to be 25 per cent less than conventional air-cooled motorpumps. The firm also has an-

**Linde Co., a Division of Union Carbide Corp., is using the Flame-Plating gun shown in a special process for protecting metal parts against wear, abrasion, and corrosion. The gun blasts tiny particles of tungsten carbide or aluminum oxide onto metal surfaces. The process is a regular part of Lockheed Aircraft Corporation's F-104A production procedure. Coatings of 0.002 to 0.010 in. can be built up by successive applications and can be finished to a smoothness of 1–2 microin. r.m.s., according to the division.**






One of America's offshore radar warning towers—Texas Tower III—built by Walsh Holyoke Division, Continental Copper and Steel Industries, Inc.

# ...with each seam checked on Kodak Industrial X-ray Film, Type AA

2700 tons of island rest on these 272-foot welded caissons. With giant seas and howling gales to stand against, every seam must be sound. Radiography provided the evidence of each weld's quality.

Each weld was radiographed using a 10 curie pill of cobalt 60. And because Kodak Industrial X-ray Film, Type AA, provides greatly increased film speed, exposure times could be moderate.

While giving speeds up to twice that of the former Kodak Type A Film, this new film retains the fine sensitivity characteristics which made Type A the most widely used x-ray film in industry.

Your x-ray dealer and the Kodak Technical Representative will gladly tell you how this new film can improve your radiographic operation and help you get more out of your present x-ray or gamma-ray equipment. It can pay you to get in touch with them.

**Read what the new Kodak Industrial X-ray Film, Type AA, does for you:**

- Reduces exposure time—speeds up routine examinations.
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- Gives greater subject contrast, more detail and easier readability when established exposure times are used with reduced kilovoltage.
- Shortens processing cycle with existing exposure technics.
- Reduces the possibility of pressure desensitization under the usual shop conditions of use.

**EASTMAN KODAK COMPANY**
***X-ray Division*, Rochester 4, N. Y.**

For welding, Kodak Industrial X-ray Film, Types AA, M, and K, are available in the new 70mm by 550 ft. package.

Kodak
TRADE MARK

nounced the appointment of Ben W. Badenoch as General Manager of the new Aero Hydraulics Division.

• **Vitro Corporation of America,** Thieblot Aircraft Company division, has developed a new in-flight refueling system said to extend the range of current and future tactical aircraft. The system includes a Flying Pipe unit to enable a jet fighter to transfer fuel to another fighter at altitudes above 30,000 ft. and at speeds over 530 m.p.h. The system includes a refueling package designed for attachment to the underside of any ordinary jet aircraft wing and for quick jettisoning, the firm reports.

• **Western Gear Corporation** has announced the appointment of Philip D. Terry as Marketing Manager, Aircraft & Missile Products, Eastern States region.

• **Westinghouse Electric Corporation** has opened a new plant to design and build small quantities of special prototype electronic transformers to customer specifications. The firm also announced establishment of a Reactor Evaluation Center near Pittsburgh, Pa. Its East Pittsburgh plant is the site of the state's first privately licensed heliport, the firm reports. A pulse testing modulator has been installed by the Specialty Transformer Department to test insulation and response characteristics of high-power pulse transformers used with klystron and magnetron loads. Two new silicon power rectifiers, Types 302 and 303, are now available with hermetically sealed cells providing d.c. currents up to 35 and 22 amp. halfwave, and with a maximum peak inverse voltage up to 600 volts. W. H. Brandt has been named Director of Advanced Systems Engineering for the Westinghouse Sunnyvale manufacturing division. R. K. Collins has been appointed South Pacific Division Aviation Manager with headquarters at the company's Los Angeles, Calif., office.

**Harold T. Luskin discussed "The Airplane and the Rocket—Where They Are Going," before 110 members and guests at the May 15 meeting of the Antelope Valley Subsection of the Los Angeles Section. Mr. Luskin is Assistant Chief, Aerodynamics Section, Santa Monica Division, Douglas Aircraft Co., Inc.**

## IAS SECTIONS

***Antelope Valley Subsection of the Los Angeles Section***

### Flight-Test Group Organizes Subsection

Institute members in the Palmdale, Lancaster, Mojave, and Edwards AFB, Calif., area established the Antelope Valley Subsection of the Los Angeles Section with an initial meeting at Lancaster on April 11.

The subsection represents the major aircraft experimental flight-test group in the nation. Officers selected by an organizing committee include Chairman—Walter C. Williams, NACA High Speed Flight Station; Vice-Chairman—A. B. Carder, Douglas Aircraft Company; Treasurer—J. L. Rust, Republic Aviation Corporation; Secretary—V. L. Weaver, General Electric Company; Program Chairman—Murray O'Toole, North American Aviation, Inc.; Membership Chairman—Paul Bikle, Air Force Flight Test Center; and Publicity Chairman—F. J. Ross, Air Force Flight Test Center.

The most recent meeting reported by the subsection took place at Edwards AFB on June 20. Lieutenant Colonel Carlo R. Tosti, USAF, Assistant Executive Officer to the Commander, ARDC, gave a classified talk on "ARDC Briefing" before more than 300 members and guests. This meeting was cosponsored by the Society of Experimental Test Pilots and the Air Force Flight Test Center.

Harold T. Luskin, Assistant Chief, Aerodynamics Section, Douglas Santa Monica Division, discussed "The Airplane and the Rocket—Where They Are Going" before 110 members and guests on May 15.

**The Antelope Valley Subsection of the Los Angeles Section held its initial meeting on April 11. Roy E. Marquardt *(standing)*, President, Marquardt Aircraft Co., spoke on "Prelude to Power." Seated are Guest Chairman George R. Mellinger *(left)*, Manager, Flight Test, North American Aviation, Inc., and the Subsection's Chairman, Walter C. Williams, NACA High Speed Flight Station.**

He reviewed current concepts of subsonic and supersonic aircraft and hypersonic rockets, predicting commercial application in the future.

Science and math students from local high schools attended this meeting.

George R. Mellinger, Manager, Flight Test, North American, presided as Program Chairman at the April 11 meeting. Roy E. Marquardt, President, Marquardt Aircraft Company, spoke on "Prelude to Power," giving an unclassified résumé on ram-jet development. He discussed newest power plants and what may be expected from future designs before 150 members and guests.

Advice in organizing the subsection was provided by E. W. Robischon, IAS Western Region Manager; Welko Gasich, Los Angeles Section Chairman; and Mr. Mellinger.

FRANKLIN J. ROSS
*Publicity Chairman*

***San Diego Section***

### Family Night Meeting

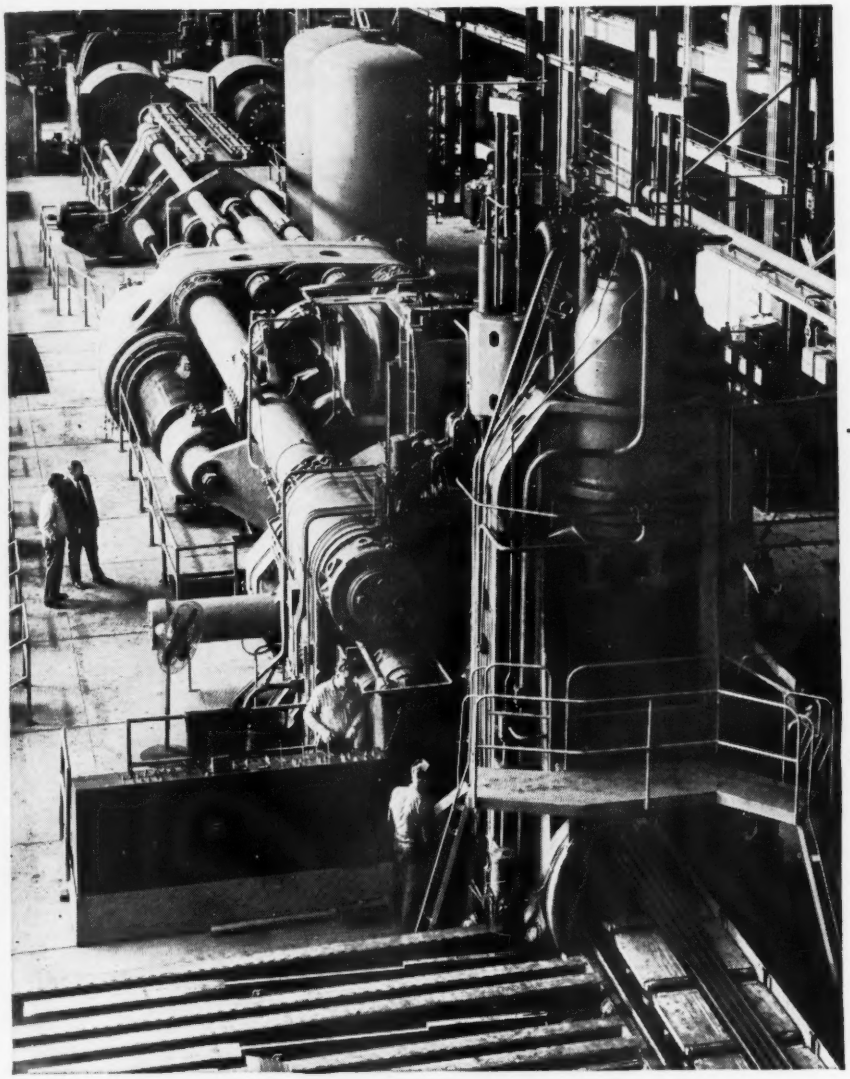
Some 150 members, wives, and children attended the annual Family Night meeting and dinner on July 2. The theme of the meeting was model airplanes.

Control line model flying was demonstrated in the parking lot, and more than 40 different models were displayed in the IAS Building auditorium.

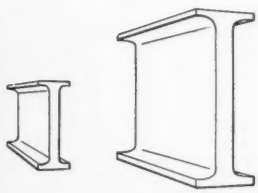
Several models and model kits were given away as door prizes and everyone received a balsa-wood glider.

Curt Smith and Bud Nelson, Ryan Aeronautical Company engineers, gave short talks on building and flying free flight, control line, and glider-type models.

Movies shown during the meeting cov ered the history of powered flight, a mode airplane meet, and the Ryan X-13 Vertijet.

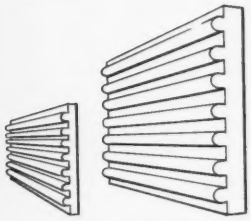


**HOW THE 13,200-TON PRESS BOOSTS EXTRUSION CAPACITY**



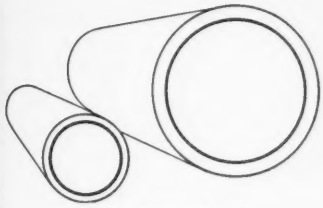
FROM 11″ TO 28″

**STRUCTURAL SHAPES**



FROM 9″ TO 20″

**STIFFENED SECTIONS**



FROM 10″ TO 24″ O. D.

**TUBING**

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If your design calls for large magnesium or aluminum extrusions, contact the nearest Dow Sales Office or write to THE DOW CHEMICAL COMPANY, Midland, Michigan, Department MA 1405C.

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*Texas Section*

### Lyman-Alpha Satellite Described by R. C. Baumann

R. C. Baumann, Head, Satellite Group, Naval Research Laboratory, spoke on "Design, Fabrication, and Testing of the First Man-Made Satellite" at the July 26 dinner meeting.

Some 130 engineers and their guests heard Mr. Baumann describe the satellite vehicle and the satellite itself. He covered the vehicle flight path and the method of spinning the nose section prior to satellite release.

The bulk of his discussion centered upon the construction of the satellite. Slides were used to show the forming, spinning, and machining operations on the magnesium hemispheres which form the outer shell. Mr. Baumann noted that extreme accuracy is required to ensure perfect balance for instrumentation accuracy.

Special advanced telemetering circuitry was designed with circuits for an eight-channel transmitter compressed into a disc 3 in. in diameter and 1/4 in. thick. This is potted in plastic and placed with other components in a balanced cylindrical stack in the satellite center. Dry batteries provide transmitter and instrumentation power for about 2 weeks, he said.

Mr. Baumann's description was of the Lyman-Alpha satellite for atmospheric, earth shape, and micrometeorite erosion measurements.

▶ "Future Trends in Aircraft Engines" were discussed by Elmer Paulson at the July 10 meeting. Mr. Paulson is Manager, Preliminary Design, Jet Engine Department, General Electric Company's Aircraft Gas Turbine Division.

The talk covered forecasts of probable speed and altitude ranges and types of engine most likely to produce them. He also discussed the possible market for new types of gas turbine for private planes. Mr. Paulson suggested that gas-turbine-powered aircraft may look like flying saucers.

Some 90 engineers attended the classified meeting.

A. T. CLEMEN
*Secretary*

## STUDENT BRANCHES

### Tri-State College

Officers for the fall term were nominated at the fourth summer term meeting on July 25, and the next day a slate was elected.

Officers elected were Chairman, Donald Scharf; Vice-Chairman, Eugene Prue; Secretary, William Berg; Treasurer, Bruce Bidelman; Tri-Angle Reporter, Robert Pemberton.

Members saw a film, *The XRON-1*, and voted for the location of the Branch summer picnic, scheduled for August 10.

▶ At the third summer term meeting, July 11, Charles Libove, Faculty Adviser discussed the next Student Paper Competition and urged members to prepare entries.

Two movies were shown—*Lethal Progress* and *Precision in Plastics*—the first showing armament on the F-89 Scorpion and the second about designing and manufacturing a small-scale plastic model of the F-89.

▶ William Berg and John Pielow were appointed to the Program Committee during a short business meeting on June 27. Mr. Pielow also was named Manager of the Branch softball team.

DONALD P. ZURFLUH, *Secretary*

## MEMBERS ELECTED

***The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the Review.***

### Elected to Associate Fellow Grade

**Follett, Samuel F.,** B.S. in Engrg., Head, Ministry of Supply Mission, British Joint Services Mission (Washington, D.C.).

**Pollicutt, Frederick H.,** Tech. Dir. & Chief Designer, Hunting Percival Aircraft, Ltd.

**Tischler, Adelbert O.,** M.S. in C.E., Head, Rocket Combustion Sect., NACA (Cleveland).

### Transferred to Associate Fellow Grade

**Braasch, Herman L.,** B.S. in C.E., Chief, Aircraft Projects, Ryan Aeronautical Co.

**Bracha, Vincent J.,** B.S. in Propulsion, Major, USAF; Graduate Student, Univ. of Chicago.

**Bradham, Robert W.,** B.S. in M.E., Proj. Engr., Power Plant, Advance Design Sect., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp.

**Drakeley, George T.,** B.S. in M.E., Sr. Group Engr., Boeing Airplane Co.

**Eckert, Hans U.,** Dipl. Engr. in Appl. Physics, Staff Scientist, Scientific Research Lab., Convair Div. (San Diego), General Dynamics Corp.

**Fahnestock, Louis, III,** B.S. in Engrg., Dir., Proj. Admin., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp. (Hagerstown).

**Fink, Daniel J.,** M.S. in Ae.E., Chief Engr., Allied Research Associates, Inc.

**Gelvin, Elvin R.,** Asst. Mgr., Flight Test Dept., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp. (Hagerstown).

**Harr, Phil I.,** B.S. in Ae.E., Quality Mgr., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp. (Hagerstown).

**Hildebrand, Robert B.,** M.S., Unit Chief, Power Plant Prelim. Design & Research, Boeing Airplane Co.

**Huber, Claude S.,** B.S. in Ae.E., Proj. Engr., Fairchild Aircraft Div., Fairchild Engine & Airplane Corp. (Hagerstown).

**Keating, Tristan J.,** M.S. in M.E., Chief, Prop. Subsystems, Propulsion Lab., WADC.

**Kirchner, Mark E.,** M.S. in Ae.E., Group Engr., Boeing Airplane Co.

**Miller, Jay W.,** Ph.D. in Ae.E., Aerodynamics Engr., Boeing Airplane Co.

**Ormsbee, Allen I.,** Ph.D. in Ae.E., Prof. of Aero. Engrg., Univ. of Illinois.

**Parks, Edwin K.,** Ph.D. in Ae.E., Assoc. Prof. in Aero. Engrg., Univ. of Kansas.

**Thurlow, David,** B.S. in M.E., Sr. Group Engr., Boeing Airplane Co.

**Weaver, Virgil L.,** B.S. in E.E., Mgr., Flight Test, General Electric Co. (Edwards AFB).

**Willson, Abner R.,** E.E., Supvr., Struct. Testing, Boeing Airplane Co.

**Withington, Holden W.,** M.S. in Ae.E., Sr. Proj. Engr., Boeing Airplane Co.

**Yeager, Donald L.,** B.S. in M.E., Asst. Chief, Field Liaison Office, Deputy Comdr., R&D, ARDC, USAF (Baltimore).

### Elected to MEMBER Grade

**Allan, Robert B.,** B.S. in Ae.E., Supvr., Engrg. and Flight Test, Republic Aviation Corp.

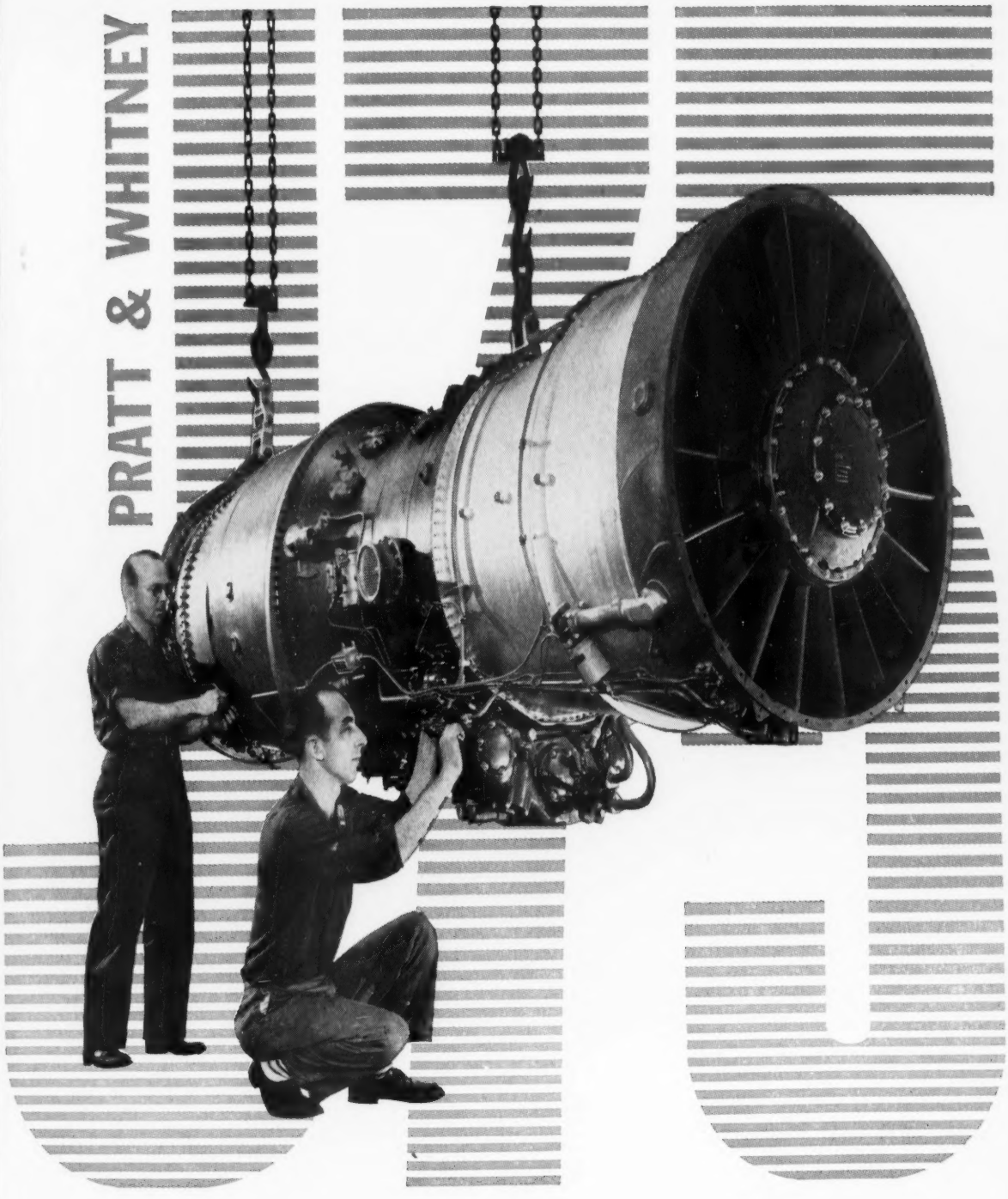
**Barton, Charles J.,** B.S. in C.E., Struct. Engr., Convair Div. (San Diego), General Dynamics Corp.

**Beauregard, John P.,** M.S. in M.E., Analytical Engr., Compressor Aerodynamics, Canadian Pratt & Whitney Co., Ltd.

**Bettens, Warern J.,** B.S., Engrg. Rep., Convair Div. (San Diego), General Dynamics Corp.

**Burns, Gene C.,** B.S. in M.E., Design Leadman, Douglas Aircraft Co., Inc. (El Segundo).

**Carroll, Francis L.,** B.S. in Ae.E., Sr. Product Planning Engr., Aircraft Accessory Turbine Dept., General Electric Co. (West Lynn).

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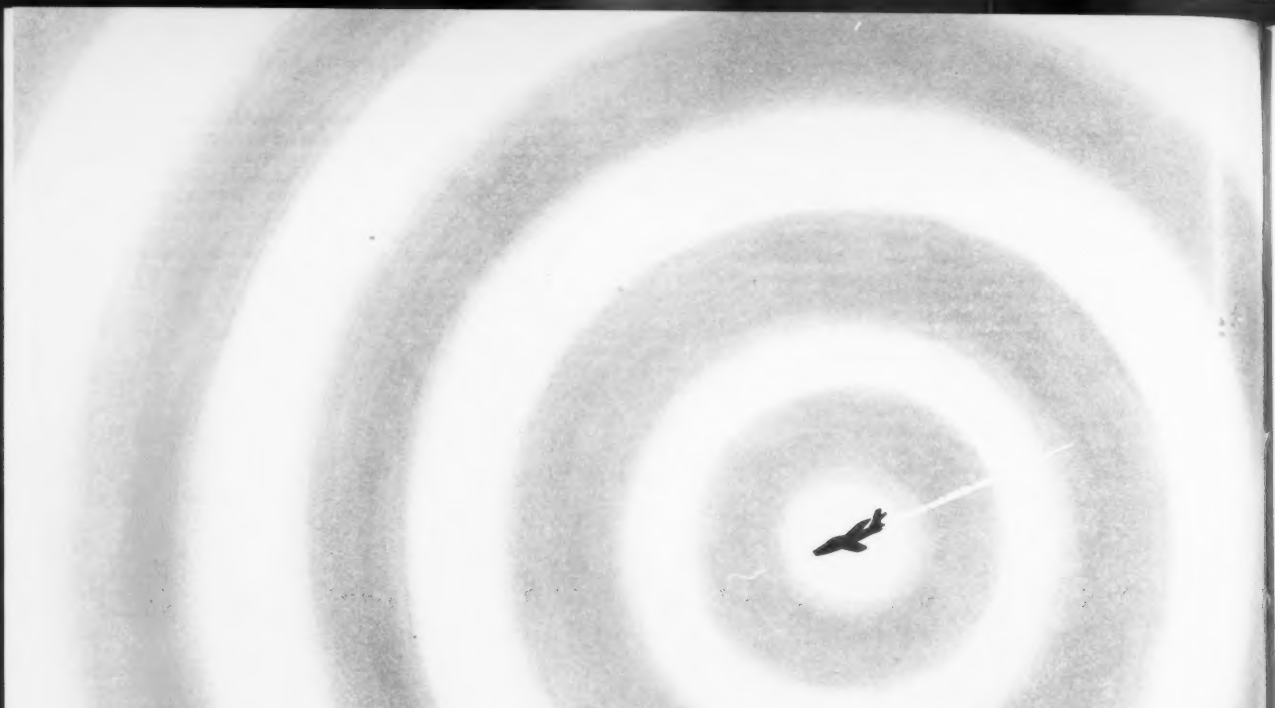

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**Carroll, James C.,** B.S. in M.E., Aerodynamic Specialist, General Electric Co. (Evendale).

**Chamberlain, Clinton J.,** M.S. in Physics, Engr., General Electric Co. (Ithaca).

**Chamberlain, Richard K.,** B.S. in Ae.E., Engr., General Tire & Rubber Co.

**Coghlan, Robert G.,** B.S. in M.E., Design Engr., Convair Div. (San Diego), General Dynamics Corp.

**Coleman, William R.,** B.S. in M.E., Experimental Test Pilot, Chance Vought Aircraft, Inc.

**Constantine, Nicholas J.,** B.S. in M.E., Tech. Engr., General Electric Co. (Washington, D.C.).

**Coppa, Anthony P.,** B.S. in M.E., Engr., Thermal Stress & Creep, General Electric Co. (Philadelphia).

**Dellar, Donald W.,** Leadman, Convair Div. (San Diego), General Dynamics Corp.

**Dienes, John K.,** B.A. in Math., Dynamicist, Minneapolis-Honeywell Regulator Corp.

**Dietz, Albert E.,** B.S. in Ae.E., Asst. Group Engr., Hayes Aircraft Corp.

**Dwyer, William L.,** B.S. in Ae.E., Functional Engr., General Electric Co. (Philadelphia).

**Flader, Deane F.,** B.S. in Ae.E., Proj. Engr., Fuel Controls, Fairchild Engine Div., Fairchild Engine & Airplane Corp.

**Frantz, Wilbert P.,** M.S. in E.E., Engrg. Dept. Head, Sperry Gyroscope Co. Div., Sperry Rand Co.

**Fuller, Roger D.,** B.A., Hydrodynamic Group Engr., Convair Div. (San Diego), General Dynamics Corp.

**Galloway, Howard L., Jr.,** B.S. in Physics, Physicist GS-12, U.S. Naval Ord. Lab. (White Oak).

**Gutshall, William D.,** B.A. in Math., Flight Test Engr., Missile Systems Div., Lockheed Aircraft Corp. (Van Nuys).

**Hafer, Xaver,** Dipl. Ing., Group Leader, Ernst Heinkel Fahrzeugbau.

**Henderson, Andrew B.,** B.S. in E.E., Staff Engr., USAF (Wright-Patterson AFB).

**Hsu, Cheng-Ting,** Ph.D. in Ae.E., Research Assoc., Univ. of Minnesota.

**Jackson, Nelson P.,** B.S., Mgr., Washington Office, Atomic Products Div., General Electric Co.

**Jaycox, Donald F.,** B.S. in M.E., Research Engr., Systems Analysis, Chicago Aerial Industries.

**Kindling, Paul K.,** Devel. Engr., Goodyear Aircraft Corp.

**Klingenhagen, John L.,** Lt. Col., Staff Officer, Office of Secy. of Defense.

**Knapp, Elton L.,** M.S. in Ae.E., Comdr., Production Mgr., Overhaul & Repair Dept., NAS (Jacksonville).

**Kwiatkowski, S. F.,** Dipl. in M.E., Chief, Stability & Control, Avro Aircraft, Ltd.

**Larson, Robert R.,** M.S. in Ae.E., Aerodynamicist, Boeing Airplane Co. (Renton).

**Lathrop, John B.,** B.A. in Math., Dept. Mgr., Company Studies, Lockheed Aircraft Corp. (Burbank).


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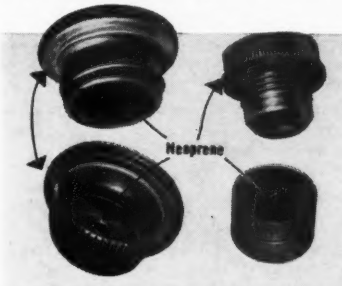


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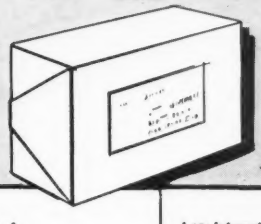
This new polyethelene closure has heavy molded threads. It fits the contour of the part and when set up by hand will maintain pressure in a system while protecting threads.



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**Lipkis, Robert,** M.S. in E., Member, Tech. Staff, Ramo-Wooldridge Corp.

**Loos, Hendricus G.,** Dr., Math. and Physics, Sr. Engr., Supersonic Group, Propulsion Research Corp.

**Ludlow, Kenneth G.,** Sr. Engr., Northrop Aircraft, Inc.

**Marshall, Maurice K.,** M.S. in M.E., Prof., Univ. of Kentucky.

**Mather, Roger F.,** S.M., Devel. Rep., U.S. Steel Corp.

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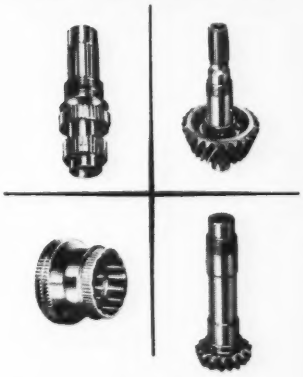

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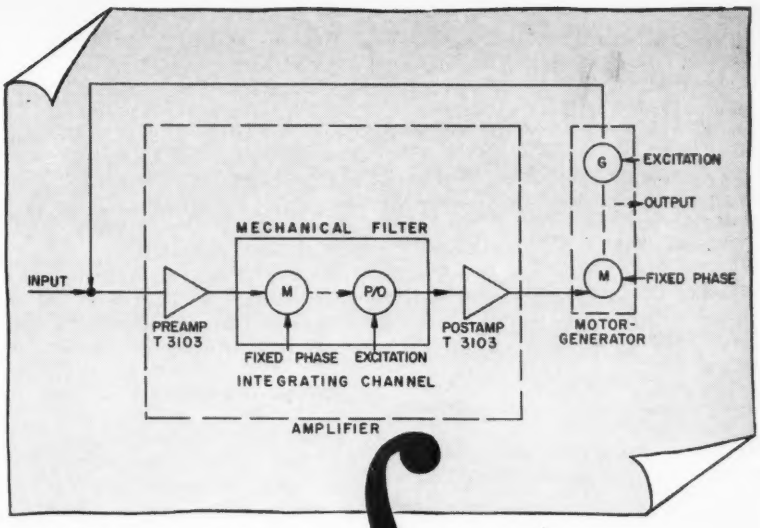


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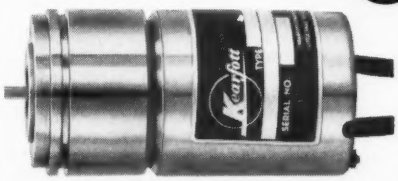

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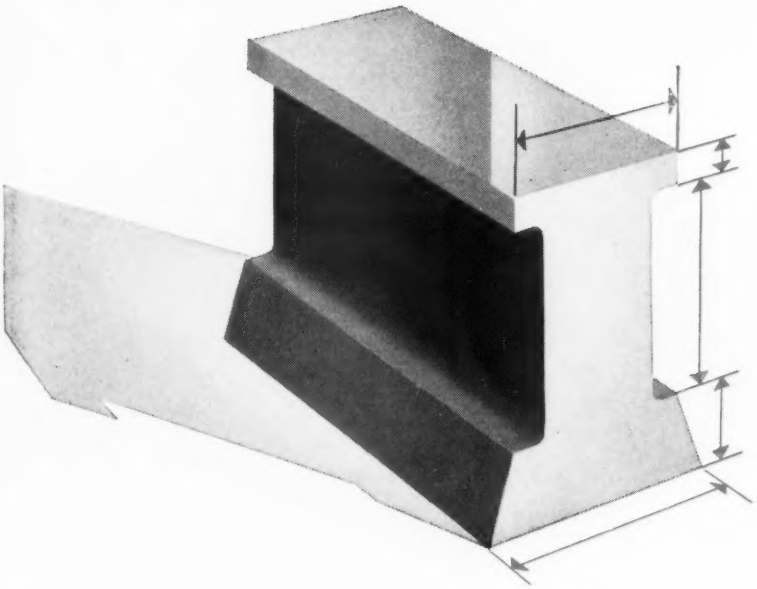

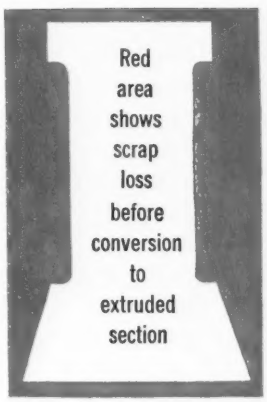


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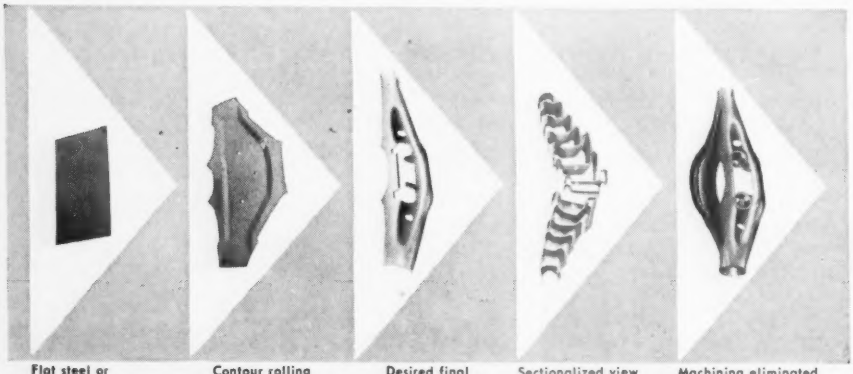

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## Acoustics, Sound, & Noise

**Noise—Payment for Progress.** Vincent Salmon. *SRI J.*, 2nd Quarter, 1957, pp. 34–40. Discussion outlining the physical characteristics of sound and the effects of sound on humans and machines as a preliminary to describing a super-loud noise generator, jet aircraft noise, and means for controlling noise.

**Reflection, Transmission, and Amplification of Sound by a Moving Medium. Appendix A—Acoustic Energy Flow in a Moving Medium. Appendix B—Two Moving Media. Appendix C—Different Densities and Speeds of Sound.** Herbert S. Ribner. *ASA J.*, Apr., 1957, pp. 435–441. Analysis for plane sound waves originating in air at rest and impinging obliquely on a plane interface with a moving stream.

**Steady Rotational Flow Generated by a Sound Beam.** Sigve Tjötta. *ASA J.*, Apr., 1957, pp. 455–458. Theoretical study of the streaming generated by an ultrasonic sound beam in a fluid.

**Perception of Vowels Heard in Noises of Various Spectra.** J. M. Pickett. (*USAF CRC TN 56-12*) [*AD 110057*] *ASA J.*, May, 1957, pp. 613–620. 11 refs.

**Concerning the Form of the Loudness Function.** S. S. Stevens. *ASA J.*, May, 1957, pp. 603–606. ONR-supported experiments to examine certain possible irregularities in the loudness function.

**Critical Band Width in Loudness Summation.** E. Zwicker, G. Flottorp, and S. S. Stevens. *ASA J.*, May, 1957, pp. 548–557. 17 refs. ONR-supported experimental investigation whose results indicate that the concept of the critical band applies to loudness summation.

**Absorption and Dispersion of Forced Spherical and Cylindrical Sound Waves According to the Navier-Stokes Equations.** R. P. Kanwal. *ASA J.*, May, 1957, pp. 593–595. ONR-supported presentation of a new version of Kirchhoff's approach to curved waves of expansion. A method is developed for adjusting Truesdell's results on plane waves so as to apply to the class of curved waves considered.

**Reflection of Plane Sound Waves from a Sinusoidal Surface.** John G. Parker. *ASA J.*, Mar., 1957, pp. 377–380. ONR-supported analysis of the problem of calculating the specular component of the sound field reflected from a sinusoidal pressure-release surface.

**On Scattering and Reflection of Sound by Rough Surfaces. Appendix—List of Papers Dealing with Other Models.** Victor Twersky. *ASA J.*, Feb., 1957, pp. 209–225. 19 refs. USAF-Army-supported analysis considering random distributions of arbitrary identical protuberances on free or rigid base planes.

**On Wave Propagation in a Random Inhomogeneous Medium.** David S. Potter and Stanley R. Murphy. *ASA J.*, Feb., 1957, pp. 197, 198. Navy-supported calculation of the coefficient of intensity variation for acoustic transmission in a randomly inhomogeneous medium.

**Kirchoff-Helmholtz Absorption in Wide and in Capillary Tubes at Audible Frequencies.** P. Mariens. *ASA J.*, Apr., 1957, pp. 442–445. 10 refs. Measurements of the acoustic amplitude attenuation constant in air for pressures ranging from 2.3 to 0.18 atmospheres, in a cylindrical tube and in cylindrical capillary tubes.

**Tube Corrections in the Study of Sound Absorption.** F. Douglas Shields and Robert T. Lagemann. *ASA J.*, Apr., 1957, pp. 470–475. 17 refs. Investigation of the absorption and velocity of sound in argon, nitrogen, and carbon dioxide over a range of frequency, pressure, and temperature conditions.

## Aerodynamics

**On a Minimum-Time Flight Path of a Jet Aircraft.** John Carstoiu. *J. Aero. Sci.*, Sept., 1957, pp. 704–706. Analysis of the problem by considering the motion, in a vertical plane, of the mass center of the aircraft, having a mass equal to that of the aircraft and acted on by a force equal to the vector sum of the external forces.

### *Boundary Layer*

**Some Aspects of Three-Dimensional Boundary Layer Flows.** R. Sedney. (*U. S. BRL Rep. 962*, Sept., 1955.) *Quart. Appl. Math.*, July, 1957, pp 113–122. 13 refs. Analysis of the equations for boundary-layer flow over a general smooth surface using a normal coordinate surface. The equations are not tensors but subtensors. Conditions for the cartesian form of equations are given and a criterion for no secondary flow is found in terms of the geodesics of the body surface.

**On the Distribution of Intermittency in the Transition Region of a Boundary Layer.** Roddam Narasimha. *J. Aero. Sci.*, Sept., 1957, pp. 711, 712. Considerations suggesting an explanation of the intermittency factor $\nu$ measured by Schubauer and Klebanoff.

### *Fluid Mechanics & Aerodynamic Theory*

**The Relation Between the Flow of Non-Newtonian Fluids and Turbulent Newtonian Fluids.** R. S. Rivlin. *Quart. Appl. Math.*, July, 1957, pp. 213–215. 13 refs. OOR-sponsored discussion to form some analogy between the two types of flow, and to indicate some of the phenomena which might be observed in turbulent fluids.

**Physical Mechanism of Vortex-Ring Cascade.** Norbert J. Dabrowski. *J. Aero. Sci.*, Sept., 1957, pp. 708, 709.

**Rotational Waves in a Turbulent Liquid.** R. V. L. Hartley. *ASA J.*, Feb., 1957, pp. 195, 196. Derivation of equations for the propagation in a liquid, in a state of fine scale turbulence, of a type of so-called transverse wave in which the elasticity is associated with the rotation of an element rather than with its shearing as in a solid.

**Flow Over Blunt-Nosed Bodies.** Robert W. Truitt. *J. Aero. Sci.*, Sept., 1957, pp. 709, 710.

**Shock Hugoniot of Air.** W. E. Deal. *J. Appl. Phys.*, July, 1957, pp. 782–784. Description of experiments in which an explosive-driven plate sets up a strong shock in air that is in contact with the plate. A technique is developed by determination of the dynamic pressure-compression relation for gases undergoing such shocks.

**Two-Dimensional Bow Shock Wave Detachment Distances.** R. A. A. Bryant and J. N. G. Grant. *J. RAeS*, June, 1957, pp. 424–426. 15 refs. Experimental investigation made by means of a hydraulic analogy to determine the feasibility of evaluating the effects of acceleration on detachment distance.

**On the Velocity Profile for Turbulent Flow Near a Smooth Wall.** John W. Miles. *J. Aero. Sci.*, Sept., 1957, p. 704. Derivation of a calculation method as an alternative to Van Driest's continuous expression and based on a modification of Prandtl's original hypothesis.

### *Internal Flow*

**The Secondary Flow Behind a Cascade.** S. Soundranayagam. *J. Aero. Sci.*, 1957, pp. 706, 707. Extension of the vortex filament concept to the case of diffusing or accelerating cascades to show that the resultant secondary circulation is zero for an impulse cascade.

**Turbulence Theory in the Light of the Circular Pipe Flow.** Max M. Munk. *Catholic U. Am., Paper*, May, 1957. 26 pp. 8 refs. ONR-supported comparison of Munk's turbulence theory with Nikuradse's classical pipe-flow tests. The results show that the lump size varies, in general, in proportion to the square root of the wall distance.

**On the Existence of Periodic Waves Near Critical Speed.** Walter Littman. *Commun. on Pure & Appl. Math.*, May, 1957, pp. 241–269. 14 refs. OOR-supported analysis to determine the existence of permanent periodic waves in a channel of finite depth with a horizontal bottom. Two-dimensional flow that can be represented by a complex potential function is studied, and gravity and pressure forces are the only ones acting on the fluid.

**Investigation of a Vortex Tube.** A. P. Merkulov. *Soviet Physics - Tech. Physics*, No. 6, 1957, pp. 1,243–1,248. Translation. Experiments to find the optimum length of a counter-flow vortex tube with a diameter of 33 mm. and to determine the influence of various distinct factors on its operation.

### *Natural Flight*

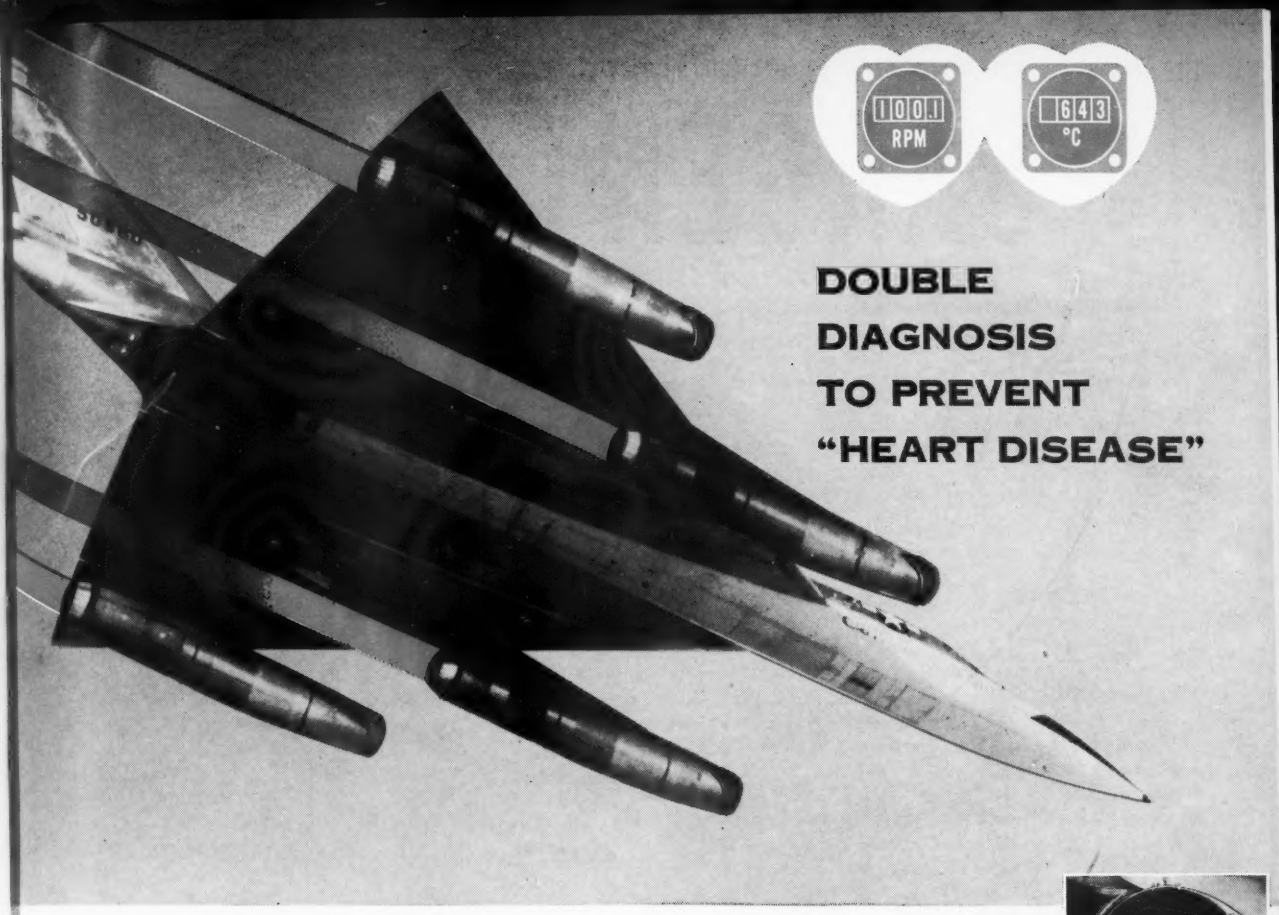
**Bird Tails.** John Barlee. *Shell Av. News*, May, 1957, pp. 2–5. Discussion of the role tail feathers play in the flight regime of birds. Several types of tail are studied, and analogies are drawn between these configurations and various aircraft control and lift systems.

### *Wings & Airfoils*

**Tunnel-Wall Effect on an Aerofoil at Subsonic Speeds.** A. Thom and Laura Klanfer. *Gt. Brit., ARC R&M 2851*, (Aug., 1951) 1957. 19 pp. 11 refs. BIS New York, $1.08. Study of wall effects on flow past a symmetrical airfoil at zero incidence for the incompressible and compressible cases.

**Second-Order Subsonic Airfoil Theory Including Edge Effects.** Milton D. Van Dyke. *U.S., NACA Rep. 1274*, 1956. 23 pp. 43 refs. Supt. of Doc., Wash., $0.30. Solutions for a number of airfoils and comparison of the results with those of other theories and experiments. A

(*Continued on page 128*)

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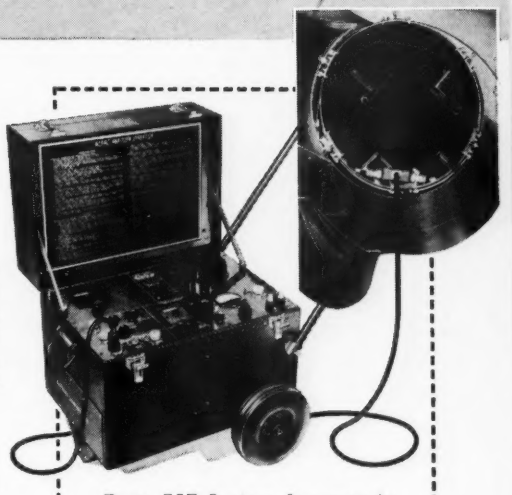

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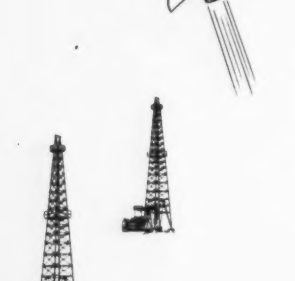

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Volume 2, Number 10 October, 1957


### ACOUSTICS, SOUND, & NOISE

**EFFECT OF A REFLECTING PLANE ON THE POWER OUTPUT OF SOUND SOURCES.** Uno Ingard and G. L. Lamb, Jr. ASA J., June, 1957, pp. 743, 744. ARDC-sponsored calculation of the "power amplification factor" - the effect of a reflecting plane boundary on the power output of a sound source located above it - for a number of elementary sound sources (monopole, dipole, and longitudinal quadrupole) as a function of the distance between the plane and the source. Special attention is given to evaluating the source height yielding minimum power output and to the ratio between the maximum and minimum power radiated.

**ACOUSTICAL RADIATION PRESSURE DUE TO INCIDENT PLANE PROGRESSIVE WAVES ON SPHERICAL OBJECTS.** G. Maidanik. ASA J., June, 1957, pp. 738-742. USAF-supported application of Westervelt's general formulation to compute the expression for the force exerted on a scattering sphere by a plane progressive wave. The expression is general in the sense that it allows for complex refractive index and variation of the effective densities of the sphere relative to that of the surrounding medium. The numerical calculations are confined to the case of "hard" and "soft" spheres only.

**SOUND TRANSMISSION THROUGH THIN CYLINDRICAL SHELLS.** P. W. Smith, Jr. ASA J., June, 1957, pp. 721-729. 10 refs. ONR-supported analysis of the impedance presented by a thin, cylindrically elastic shell to a pressure or normal stress, as a function of the axial wavelength and the angular dependence of the forces. Data are presented graphically and used to compute a measure of the sound transmitted through the shell immersed in air for various particular cases. The theory of the scattering and absorption of waves incident upon a cylinder at angles other than normal is developed for this purpose.

**ACOUSTIC IMPEDANCE OF A HELMHOLTZ RESONATOR AT VERY HIGH AMPLITUDE.** D. A. Bies and O. B. Wilson, Jr. ASA J., June, 1957, pp. 711-714. OSR-supported experimental investigation of the acoustic impedance of a Helmholtz resonator terminating a 10-in. -diam. tube, for sound pressure levels in the resonator from 100 db. to 170 db., and for a range of particle velocities in the neck from 1.3 to 1.2 x $10^4$ cm./sec. (r.m.s.). Two different mounting orientations show the same general rise in acoustic resistance and in resonant frequency with increasing sound-pressure level, but give quite different results in detail.

### AERODYNAMICS

**METOD RESHENIA URAVNENII NEUSTANOVIVSHEGOSIA TECHENIIA GAZA S UCHETOM DISSIPATIVNYKH PROTSESSOV V OBSCHEI TEORII OTNOSITEL'NOSTI.** T. Aitmurzaev. AN SSSR Dokl., Apr. 1, 1957, pp. 769-772. In Russian. Derivation of a method for solving unsteady gas flow equations with allowance for dissipative processes in the general theory of relativity.

#### Aerothermodynamics

**LE PROBLEME DE L'ECHAUFFEMENT CINETIQUE.** G. Lehr. Docaéro. June, 1957, pp. 3-20. In French. Study of the problem of kinetic heating with the introduction to the calculation including the recovery coefficient, Van Driest formula, Stanton Number, and Reynolds analogy coefficient. The case of a flat plate covers expression of the recovery coefficient and the Stanton Number in laminar and turbulent flows, friction and analogy coefficient, and diagrams to simplify the calculation. Includes analysis of boundary-layer control and development of a method to stabilize transition by cooling. It is concluded that by delaying the boundary-layer transition not only the kinetic heating is lowered considerably but also the whole performance of the winged body moving with great velocity is improved. Problems involving temperature considerations as in the case of fuel, oil, rubber, and electronics are simplified, structural weights decreased, and fuel consumption for a given velocity and a given range is lowered.

METHODES D'EXPLORATION DYNAMIQUE ET THERMIQUE ET ETUDE DE LA COUCHE-LIMITE LAMINAIRE COMPRESSIBLE DE LA PLAQUE PLANE. Max Plan. France, Min. de l'Air PST 331, 1957. 123 pp. 83 refs. SDIT, 2, Av. Porte-d'Issy, Paris 15, Frs. 1,500. In French. Development of methods of dynamic and thermal exploration and study of the compressible laminar boundary layer over a plate. Includes systematic study of local velocity and temperature measurements in the boundary layer, review of methods for the theoretical determination of these values, selection of a specific method and presentation of obtained numerical values, comparison of theoretical and experimental results for the laminar boundary layer, analysis of the influence of the leading-edge, thickness, compilation of numerical values of physical properties of air encountered in the calculation, and variations with temperature.

DEVELOPMENT AND APPLICATION OF A TECHNIQUE FOR STEADY STATE AERODYNAMIC HEAT TRANSFER MEASUREMENTS. Appendix A - HEAT METER CONSTRUCTION. Appendix B - SAMPLE RADIATION CALCULATION. F. W. Hartwig. GALCIT Memo. 37, June 1, 1957. 48 pp. 13 refs. OOR-sponsored development of a method applicable to measurements on a hemisphere cylinder. Instrumentation consists of a miniaturized thermopile of silver-constantan thermocouples approximately 1/8-in. x 1/16-in. x 1/100-in. The heat meters are installed in both a ceramic hemisphere cylinder and in a similar metal one, and three different heat-flow rates are obtained at each of six different tunnel-pressure/temperature combinations. Results are shown to be in good agreement with those predicted by Lees based on the assumption of local similarity. The repeatability of readings with the described device is found to be excellent.

FLIGHT MEASUREMENTS OF BOUNDARY-LAYER TEMPERATURE PROFILES ON A BODY OF REVOLUTION (NACA RM-10) AT MACH NUMBERS FROM 1.2 TO 3.5. Appendix - DERIVATION OF EQUATIONS USED IN DATA REDUCTION. A. G. Swanson, J. J. Buglia, and L. T. Chauvin. US, NACA TN 4061, July, 1957. 40 pp. 13 refs. Tests using the NACA RM-10 as a rocket-propelled model. Boundary-layer static-temperature profiles are determined from total-temperature measurements made with a series of probes mounted circumferentially around the body near the rear end, and from Mach Number profiles obtained from a total-pressure rate at the same body axial location. Skin-friction coefficients are determined from the total-pressure data by using both experimental and theoretical temperature profiles. Heat-transfer measurements indicate a transition from laminar to turbulent flow at a body station corresponding to a Reynolds Number of about $15 \times 10^6$.

SOME METHODS OF EVALUATING IMPERFECT GAS EFFECTS IN AERODYNAMIC PROBLEMS. G. A. Bird. Gt. Brit., RAE TN Aero. 2488, Jan., 1957. 31 pp. Development of simple numerical and graphical procedures for calculation of the imperfect gas effects on the properties of steady and unsteady one-dimensional isentropic flows, the Prandtl-Meyer expansion round a corner, and normal and oblique shock waves. The fundamental equations of each type of flow are arranged in a form in which they may be solved using the published tables of the equilibrium properties of gases. Both thermal and caloric imperfections are taken into account, but relaxation-time effects are neglected.

MASS-TRANSFER COOLING IN HIGH-SPEED LAMINAR COUETTE FLOW. E. R. G. Eckert and P. J. Schneider. U. Minn. Inst. Tech., Dept. Mech. Eng. HTL TR 12, April, 1957. 44 pp. Theoretical investigation of high-speed laminar Couette flow with injection of a light-weight foreign gas. Solutions are given for the velocity, concentration, and temperature profiles in the flow between two parallel porous plates, one of which is stationary and the other of which moves in its own plane with a constant velocity. The Couette-flow results are used to derive expressions for the skin-friction coefficient, Nusselt Number, recovery factor, and wall temperature for arbitrary injection rates and coolant reservoir temperatures. Specific calculations are made for the cases of air-to-air, hydrogen-to-air, and helium-to-air injection under both isothermal and nonisothermal flow conditions, and these results are compared directly, with good agreement, to the corresponding exact boundary-layer solutions.

HEAT TRANSFER IN A LAMINAR BOUNDARY LAYER AT MACH 2.5 FROM A SURFACE HAVING A TEMPERATURE DISTRIBUTION. Appendix - OUTLINE OF THE THEORY OF CHAPMAN AND RUBESIN. B. N. Pridmore-Brown. UTIA Rep. 45, Feb., 1957. 66 pp. Measurements made on the outer surface of a hollow cylinder with a sharp leading edge. The surface of the model is divided into 1/2-in. segments in order to make possible the control and individual measurement of the temperature of each segment. Boundary-layer pitot traverses are made on a rectangular-mouthed probe and the increase in boundary-layer thickness due to heat transfer from the model to the flow is found to be greater than that predicted by theory. A temperature recovery factor of .877 is obtained for the first element.

NON-LINEAR INTERACTIONS IN A VISCOUS HEAT CONDUCTIVE COMPRESSIBLE GAS. Boa-Teh Chu and L. S. G. Kovasznay. Johns Hopkins U., Dept. Aero., Rep., 1957. 51 pp. 14 refs. USAF-Navy-supported development of a theory by which nonlinear phenomena can be readily classified and their effects in any particular flow field easily assessed. Such a system, evolving interactions of an arbitrary order, is presented and the second-order (bilateral) interactions are investigated in detail. A method for estimating the relative importance of the different second-order (bilateral) interactions is investigated in detail and illustrated with an example. Some predictions are made about the general behavior of the flow.

OB USTANOVIVSHEISIA TEMPERATURE PLOSKOI PLASTINKI OBTEKAEMOI REAGIRUIUSHCHEI GAZOVOI SMES'IU. E. P. Vaulin. AN SSSR Dokl., Apr. 21, 1957, pp. 1,235-1,238. In Russian. Study of the problem concerning the steady temperature of a flat plate placed in a stream of reacting gas mixtures. The temperature is determined by solving a system of boundary-layer equations. The concentration and temperature profiles for the heterogeneous reaction occurring in the diffusion area are also determined.

## Boundary Layer

EXPERIMENTAL INVESTIGATION OF THICK, AXIALLY SYMMETRIC BOUNDARY LAYERS ON CYLINDERS AT SUBSONIC AND HYPERSONIC SPEEDS. R. L. Richmond. GALCIT Memo. 39, June 20, 1957. 66 pp. 16 refs. OOR-sponsored experimental investigation, carried out in two subsonic wind tunnels and in the GALCIT 5- x 5-in. hypersonic wind tunnel, to determine the transverse curvature effect on laminar and turbulent axially symmetric boundary layers. Subsonic turbulent skin-friction coefficients are estimated from velocity profiles with axial flow, on a 0.024 in.-diam. cylinder and a 1-in. -diam. cylinder; hypersonic laminar and turublent skin-friction coefficients with axial flow on an insulated 0.250-in. -diam. cylinder are measured by the floating-element technique; and turbulent skin-friction coefficients are estimated from pitot profiles with axial flow on a 0.064-in. -diam. cylinder and on a 0.024-in. -diam. cylinder at $M_1 = 5.8$.

LA GASDINAMICA DELLE MISCELE NELL'APPROSSIMAZIONE DELLO STRATO LIMITE. L. G. Napolitano. L'Aerotecnica, Apr., 1957, pp. 73-86. 14 refs. In Italian. Derivation of the boundary-layer equations for a two-component gas mixture, under the assumption that neither chemical reactions nor changes of state take place. Dimensional analysis indicates the dependence of the solution on Reynolds, Mach, Schmidt, and Prandtl Numbers and on the thermodiffusion factor. Proofs are given of the validity of the Crocco-Busemann energy integrals and of the possibility of establishing analogies between energy, mass, and momentum transfer. Conditions under which these integrals and analogies hold are derived.

NOTE ON THE BREAKDOWN OF THE LAMINAR SEPARATION BUBBLE ON THE NOSE OF A THIN WING. R. A. Wallis and N. Ruglen. Australia, ARL AN 161, May, 1957. 28 pp. Investigation of flow over the leading edge of a thin wing which shows that nose stalling is a direct result of turbulent separation near the leading edge for moderate to high Reynolds Numbers. The influence of the laminar separation bubble on these results is also discussed.

A THEORETICAL INVESTIGATION OF LAMINAR SEPARATION IN SUPERSONIC FLOW. G. E. Gadd. J. Aero. Sci., Oct., 1957, pp. 759-771, 784. 15 refs. Extension of Stratford's method to investigate the effects of Mach Number, Reynolds Number, wall temperature, and surface curvature on laminar separation in supersonic flow. Two-dimensional flows only are considered; where the surface is curved the generators are perpendicular to the flow. The wall temperature is taken to be uniform and it is assumed that separation is of the usual type for supersonic flow, taking place well upstream of the shock wave or other agency which provokes separation.

MEASUREMENT OF TRANSITION ON A SPHERE AT HIGH REYNOLDS NUMBERS. E. Y. Hsu and M. S. Macovsky. US, Navy Dept., David Taylor Model Basin, Rep. 1110, June, 1957. 12 pp. Hot-wire survey on a smooth 18-in. sphere to determine the position of boundary-layer transition from laminar to tubrulent flow. Tests run both in the towing basin and in the transonic wind tunnel, at Reynolds Numbers from $2.2 \times 10^6$ to $3.5 \times 10^6$ (based on diameter), indicate transition in a region of 90° from stagnation. This result is in agreement with predictions based on neutral stability theory.

URAVNENIIA TREKHMERNOGO POGRANICHNOGO SLOIA V SZHIMAEMOM GAZE DLIA PROIZVOL'NOI POVERKHNOSTI. V. V. Struminskii. AN SSSR Dokl., May 11, 1957, pp. 271-274. In Russian. Derivation of equations for a three-dimensional boundary layer in a viscous compressible gas for an arbitrary space. Includes transformations used for reducing the equations to a form analogous to that of equations for the three-dimensional boundary layer in a viscous incompressible fluid.

A POWER-SERIES SOLUTION FOR THE UNSTEADY LAMINAR BOUNDARY-LAYER FLOW IN AN EXPANSION WAVE OF FINITE WIDTH MOVING THROUGH A GAS INITIALLY AT REST. Appendix A - FREE-STREAM RELATIONS IN THE EXPANSION FAN. Appendix B - BOUNDARY LAYER BEHIND SHOCK OR ZERO-THICKNESS EXPANSION WAVE MOVING INTO FLUID AT REST. N. B. Cohen. US, NACA TN 3943, June, 1957. 56 pp. 18 refs. Study of the equations of motion and energy for the laminar boundary-layer flow in an expansion wave of finite width moving into undisturbed fluid, such as that in a shock tube. Solutions in the form of infinite power series for velocity and local enthalpy functions are indicated, and the first three terms of each series are evaluated. Validity of the numerical results is restricted to the leading edge of the expansion wave. Skin friction and heat transfer are compared with values given by a solution which considers the expansion wave as equivalent to a line discontinuity across which existence of isentropic expansion relations is assumed. These solutions are shown to be very different, qualitatively as well as quantitatively.

THREE-DIMENSIONAL BOUNDARY LAYER EQUATIONS. Lakshmi Sanyal. ZAMM, May-June, 1957, pp. 169-177. Rigorous derivation, following Schmidt and Schröder, of the three-dimensional boundary-layer equations on a surface. The equations are obtained with a minimum number of previously stated hypotheses. The parallel system of coordinates is used and the equations are deduced in these coordinates.

THE FLOW OF FLUID ALONG CYLINDERS. J. C. Cooke. Quart. J. Mech. & Appl. Math., Aug., 1957, pp. 312-321. 11 refs. Presentation of boundary-layer equations for uniform flow parallel to the generators of any cylinder without cylinder corners The equations are given in the form of a series of linear, third-order differential equations. The first three terms are the same as those obtained by Seban and Bond for a circular cylinder and solved by Kelly. The rest have additional terms depending on the radius of curvature of the cylinder and its derivatives. The problem is also attacked by a Pohlhausen method as far as four terms of the series. Explicit calculations are made for the drag of an elliptic cylinder of eccentricity $\sqrt{3}/2$. There is evidence that this drag is everywhere less than that of a circular cylinder of the same perimeter.

A THEORY FOR BLOWN AIRFOILS AND AIRFOILS WITH POROUS FLAPS. N. Patraulea and E. Larisch. Rev. Méc. Appl., No. 2, 1956, pp. 15-21. Analysis considering, on the basis of the theory of almost rectilinear wake flows, the two-dimensional flow about an airfoil in the vicinity of which there is a permeable surface characterized by a difference of pressure between its two sides. It is assumed that the vortex in the wake is constant on the same parallel line to the mean direction of the wake and that free vortices are generated and form a rectilinear airfoil, and another method is presented which may be used when the conformal mapping of the exterior of the airfoil on a standard region is not known.

A GENERAL INTERPRETATION OF ONE-DIMENSIONAL FLOW THEORY. Charles Lee Dailey. U. So. Cal., Paper, 1957. 34 pp. Analysis showing that one-dimensional flow theory can be developed rigorously from the general equations of fluid mechanics without employing thermodynamic variables in any but the classical equilibrium sense. It is suggested that an approximate description of actual non-equilibrium flows, to the extent possible within the framework of one-dimensional theory, can be expressed in terms of equivalent equilibrium variables. It is shown that the suggested procedure leads to an unambiguous definition of all of the one-dimensional flow variables. Application to diffuser efficiency shows the resulting definition to be related to accelerating force exerted by the diffuser.

## Fluid Mechanics & Aerodynamic Theory

THE TRANSITION PROCESS AND OTHER PHENOMENA IN VISCOUS FLOW. E. R. Lindgren. Ark. Fys., No. 1 (AFOSR TN 57-290) [AD 132361], 1957. 169 pp. 123 refs. Experimental investigation of liquid flow, conducted mainly in cylindrical tubes and using bentonite sols. Includes investigation of the properties of these bentonite sols; pressure-drop measurements and visual observations to confirm Schiller's and Binnie's results on the transition from laminar to turbulent flow; visual studies of some effects of various protuberances in tube flow; simultaneous observations of the transition process at various pairs of locations along long cylindrical tubes; and studies of the onset of turbulence by means of simultaneous pressure-drop measurements at several locations along long cylindrical tubes.

WAVE PROPAGATION AND THE METHOD OF CHARACTERISTICS IN REACTING GAS MIXTURES WITH APPLICATIONS TO HYPERSONIC FLOW. Boa-Teh Chu. Brown U., Div. Eng. (USAF WADC TN 57-213) [AD 118350], May, 1957. 48 pp. 14 refs. Presentation of characteristic relations for two-dimensional and axially symmetric flow of a reacting mixture and for one-dimensional unsteady motion in ducts of slowly varying cross-section. How these relations may be used in actual computation is briefly discussed. In the limiting case of very fast reactions, it is shown that the mixed composition approaches the local equilibrium composition, which depends only on the local density and entropy of the mixture. The discontinuous change in the sound speed when one goes from a near-equilibrium flow to equilibrium flow is examined in detail. It is shown that for the near-equilibrium flow the equilibrium sound speed is not the wave-front velocity, but rather the phase velocity. Furthermore, although the wave front in the near-equilibrium flow still propagates at the sound speed, the bulk of the disturbances propagate at the equilibrium sound speed.

NEKOTORYE VARIATSIONNYE ZADACHI GAZOVOI DINAMIKI OSESIMMETRICHNYKH SVERKHZVUKHOVYKH TECHENII. Iu. D. Shmyglevskii. Prikl. Mat. i Mekh., Mar.-Apr., 1957, pp. 195-206. In Russian. Study of variational problems of gasdynamics of axisymmetric supersonic flows. The study includes determination of a body of least wave drag and derivation of appropriate equations.

O PROSTRANSTVENNYKH SVERKHZVUKOVYKH TECHENIIAKH GAZA, IZOBRAZHAEMYKH V OBLASTI GODOGRAFA SKOROSTI POVERKHNOST'IU. I. M Iur'ev. Prikl. Mat. i Mekh., Mar.-Apr., 1957, pp. 303, 304. In Russian. Derivation of solutions of three-dimensional supersonic flow equations including conical flows and taking into account Busemann's representation.

USE OF THE GAS-HYDRAULIC ANALOG FOR THE STUDY OF GAS DYNAMICS. B. G. Broude. Sov. Phys. - Tech. Phys., No. 7, 1957, pp. 1,538-1,553. 28 refs. Translation. Study of a method to compute the flow of water by the methods of gas dynamics and to study the properties of gas flow by means of hydraulic models. The pressure distribution over a contour is obtained using the point wash-off method. From this, other aerodynamic characteristics are calculated, taking into account the effect of viscosity, surface tension, and inertia of the model water stream.

INVESTIGATION OF FLOW AROUND SIMPLE BODIES IN HYPERSONIC FLOW. Toshi Kubota. GALCIT Memo. 40, June 25, 1957. 91 pp. 21 refs. OOR-sponsored application of the flow-similarity concept to the hypersonic small-disturbance equations in order to analyze the flow around slender, blunt-nosed bodies. To verify the theoretical re-

sults, an experimental investigation is conducted for the flow around "similar-flow" bodies at Mach Number 7.7 in the GALCIT hypersonic wind tunnel. The surface pressure distributions obtained therefrom agree closely with the theoretical predictions after a simplified correction is made for the boundary-layer displacement effect.

APPLICATION OF THE THIN-WING-EXPANSION METHOD TO THE COMPRESSIBLE FLOW PAST PROFILES OF ARBITRARY SHAPE. Humio Naruse. Phys. Soc. Japan J., Aug., 1957, pp. 959-968. 17 refs. Derivation of formulas to the third approximation for the velocity distribution over the surface of an obstacle of arbitrary shape using Imai's thin-wing-expansion method. Applications are made to flow past an elliptic cylinder. The formulas, together with the $\psi$ procedure (stream function) and the $\phi\psi$ procedure (combination velocity potential and stream function), are applied to the flow past Tomotika-Tamada's profiles. The results are compared with Tomotika-Tamada's exact solutions as well as with Takami's numerical results obtained by various approximate methods. Convergency and accuracy are good up to high Mach Numbers.

VARIATSIONNAIA ZADACHA GAZODINAMIKI OSESIMMETRICHNYKH SVERKHZVUKOVYKH TECHENII. Iu. D. Shmyglevskii. AN SSSR Dokl., Mar. 21, 1957, pp. 520-522. In Russian. Study of a variation problem in gas dynamics of axially symmetric supersonic flows. A body of revolution in a sonic stream is considered and the shape of the part of that body possessing the least wave drag as well as of the minimum-loss nozzle are determined.

THE DRAG COEFFICIENT OF VERY HIGH VELOCITY SPHERES. A. J. Hodges. J. Aero. Sci., Oct., 1957, pp. 755-758. Application of velocity measurements for spheres of two sizes to calculate the drag coefficient in the range Mach 2.2 to Mach 9.7. Firings are made from a light-gas gun into open air. Results indicate that, at Mach Numbers from 4 to 10, the drag coefficient is nearly constant and equal to 0.359.

OBTEKANIE KRUGOVOGO TSILINDRA S OTOSHEDSHEI UDARNOI VOLNOI. O. M. Belotserkovskii. AN SSSR Dokl., Mar. 21, 1957, pp. 509-512. In Russian. Study of the flow past a circular cylinder with a detached shock wave using electronic computers to obtain maximum accuracy. The problem concerns a plane, parallel supersonic flow ($M_\infty > 1$) of ideal gas striking a circular cylinder with constant velocity $\omega_\infty$ and producing ahead of the cylinder a shock wave whose shape and position are unknown. Dimensionless values are introduced relating velocity to maximum velocity, pressure and density to stagnation pressure and density behind the shock wave, and linear dimensions to the radius of the cylinder; and the system of equations of motion, continuity, and energy is analyzed.

POTENTIAL AND STREAM FUNCTION OF A VORTEX DISK IN THE PRESENCE OF A RIGID SPHERE. J. Martinek, G. C. K. Yeh, and H. Zorn. Cambridge Philos. Soc. Proc., July, 1957, pp. 717-727. USAF-Navy-sponsored theoretical investigation of the problem of a distribution of circular vortex rings forming a disc with radially varying and circumferentially uniform strength in the presence of a spherical boundary (hydrodynamical case). For this purpose methods are presented for determining the image system and for evaluating explicitly the disturbance potential and the stream function. Exact solutions of flow problems are obtained by the combined use of the integral presentation of axially symmetric flows, such as vortex discs, and various previously derived sphere theorems.

SHOCK TUBE STUDIES OF THE DEVELOPMENT OF DETACHED SHOCK WAVES IN TRANSONIC FLOW. I. Matsunosuke Iwasaki and Kosuke Umetsu. Japan Soc. Aero. Eng. J., July, 1957, pp. 1-4. Investigation of detached shock waves ahead of wedges of 10° and 110° total angle, at Mach Numbers of 1.04 and 1.15. Results indicate that (1) in the early state the process of development is considerably influenced by wedge angle, (2) the dependency of detached shock-wave shape upon wedge angle is less pronounced as the flow Mach Number approaches one, and (3) in the absence of shock-tube wall effect, geometrically similar models, having the same value of $D/T_0$ (the nondimensional delay-time parameter), produce similar shapes of detached shock waves for the same Mach Number.

EXPERIMENTAL INVESTIGATION OF ATTENUATION OF STRONG SHOCK WAVES IN A SHOCK TUBE WITH HYDROGEN AND HELIUM AS DRIVER GASES. J. J. Jones. US, NACA TN 4072, July, 1957. 24 pp. Time-history measurements of the static pressure at several stations in the wall of a shock tube with an internal diameter of 3.75 in. Shock-wave velocity data are taken for a distance along the tube of about 120 ft. The range of the shock-wave Mach Number covered is from 5 to 10.5 and the initial pressure ahead of the shock varies from 5 to 100 mm of mercury. Hydrogen and helium are used as driver gases. It is shown that a helium-driven shock wave decays only about one-half as rapidly as a hydrogen-driven shock wave and that a severe pressure gradient which limits the testing time useful for obtaining reliable aerodynamic results, exists in the latter portion of the air flow.

ADIABATICHESKIE DVIZHENIIA SOVERSHENNOGO GAZA S UDARNYMI VOLNAMI BOL'SHOI INTENSIVNOSTI - ODNOMERNYE NEUSTANOVIVSHIESIA DVIZHENIIA. G. G. Chernyi. AN SSSR Otd. Tekh. Nauk Izv., Mar., 1957, pp. 69-81. 15 refs. In Russian. Development of a method for the approximate solution of transient plane flows with strong and weak shock waves, based on the solution of equations of motion represented in series form.

O METODACH OBLICZENIA WZAJEMNEGO ODDZIAŁYWANIA FALI ROZRZEDZENIOWEJ I FALI UDERZENIOWEJ. Jan Rościszewski. Rozprawy Inżynierskie, No. 2, 1957, pp. 241-268. In Polish, with summaries in English and Russian.

Methods for the analysis of the interaction between a shock wave and a simple rarefraction wave in a one-dimensional, unsteady flow. The solutions involve replacing the fundamental differential equations by finite difference equations. In the first case, the solution is obtained by using the auxiliary plane in which the line representing the state of the gas just behind the shock wave is determined in advance. The second method gives good approximations for small shock intensity, taking into account the reflected or transited simple rarefraction wave. Also discussed are Geiringer's method based on the Lagrangian representation as well as the Neuman's mechanical model.

## Internal Flow

AN INVESTIGATION OF DISCHARGE AND THRUST CHARACTERISTICS OF FLAPPED OUTLETS FOR STREAM MACH NUMBERS FROM 0.40 TO 1.30. A. R. Vick. US, NACA TN 4007, July, 1957. 47 pp. Theoretical and experimental study of a group of flapped auxiliary air outlets, rectangular in cross section, over a range of Mach Numbers from 0.40 to 1.30. The basic outlet configuration is unchanged and different flaps are attached at the outlet. Results are presented in the form of design charts for such variables as outlet discharge-flow ratio, flap angle, flap hinge-point location, and flap aspect ratio. Also presented are the variations of outlet-duct pressure at a zero discharge rate for different flap angles and aspect ratios.

## Stability & Control

ON THE LONGITUDINAL STABILITY OF AN AEROPLANE IN UNSTEADY STRAIGHT LEVEL FLIGHT. T. Hacker. Rev. Méc. Appl., No. 2, 1956, pp. 23-36. Comparative analysis to determine the most unfavorable evolutions as regards stability. Consideration is restricted to the behavior of the disturbances of motion parameters about the airplane c. g. - hence, to short-period phases of the disturbed motion, only. The method presented may also be applied to the phugoid motion.

## Wings & Airfoils

KRYL'IA MINIMAL'NOGO SOPROTIVLENIIA. Iu. L. Zhilin. Prikl. Mat. i Mekh., Mar.-Apr., 1957, pp. 213-220. In Russian. Study of the variational problem of wings assumed to have supersonic edges and to produce little turbulence in the oncoming flow. It is shown that the disturbed-velocity potential of the wing of minimum drag on the trailing surfaces satisfies the Laplace equations with mixed boundary conditions. This result was previously obtained by Kogan for wings with straight trailing edges, perpendicular to the oncoming flow. Results of the calculation indicate that the drag on minimum drag wings of rectangular plan form differs very little from that of plane wings.

A JET DEFLECTED FROM THE LOWER SURFACE OF AN AEROFOIL. H. J. Davies and A. J. Ross. Quart. J. Mech. & Appl. Math., Aug., 1957, pp. 291-301. Analysis of a two-dimensional, irrotational, steady motion of an infinite, perfect, incompressible fluid past a thin, symmetrical airfoil, at zero incidence to the mainstream, for the case when a jet issues from a general point on the lower surface of the airfoil at an angle to the chord. The motion in both mainstream and jet is taken to be irrotational. For determination of the mainstream flow about the airfoil and jet, the airfoil is represented by a single plane vortex sheet and the jet by a single curvilinear vortex sheet. The strength of the latter is derived by considering the flow within a jet. An iterative method of solution is suggested for the evaluation of the true jet shape and the forces on the airfoil. As an example, the lift, pressure distribution, moment coefficient, and the center of pressure are calculated for a jet exit position close to the trailing-edge, with a specific angle of ejection and momentum coefficient.

THE GEOMETRY OF WING SURFACES GENERATED BY STRAIGHT LINES AND WITH A HIGH RATE OF THICKNESS TAPER AT THE ROOT. D. Peckham. Gt. Brit. RAE TN Aero. 2451, May, 1957. 17 pp. Method for designing wings having a high rate of thickness taper at the root, while still maintaining a surface shape generated by straight lines. It is shown that the wing surface is generated by two sets of straight lines running parallel (in plan view) to the leading edge and trailing edge, respectively. The airfoil sections at all spanwise positions are part of one convex parabolic arc. Sections parallel to the maximum thickness line are part of one concave parabolic arc, cut off at the leading edge and trailing edge.

MEASUREMENT OF AERODYNAMIC LOADING ON OSCILLATING AIRFOILS IN SUPERSONIC FLOW. J. R. Martuccelli and E. Mollo-Christensen. MIT ASRL TR 77-1, June, 1957. 35 pp. Investigation to determine the effect of thickness and mean angle of incidence on the pressure distribution over a wedge oscillating in pitch in a supersonic stream. Pressure measurements are made for three Mach Numbers, three reduced frequencies, and two mean angles of incidence. The pressures are measured using (1) a thin pressure-sensitive probe which is transversed adjacent to, but not in contact with, the oscillating wedge; and (2) holes in the wedge leading to pressure pickups mounted on the wedge.

O TELAKH MINIMAL'NOGO SOPROTIVLENIIA V SVERKHZVUKOVOM POTOKE GAZA. M. N. Kogan. Prikl. Mat. i Mekh., Mar.-Apr., 1957, pp. 207-212. In Russian. Study of the minimum drag of wings and bodies in supersonic flow. The existence of surfaces, for which forces (acting on bodies bounded by these surfaces) and conditions of mass conservation can be expressed in terms of values of the velocity potential on the given surfaces, is indicated, thus reducing the problem of determining extremal characteristics of three-dimensional bodies to the two-dimensional problem.

AN ANALYTIC EXTENSION OF THE SHOCK-EXPANSION METHOD. G. D. Waldman and R. F. Probstein. Brown U., Div. Eng., USAF WADC

TN 57-214 [AD 130751], May, 1957. 74 pp. 20 refs. Consideration of the problem of calculating approximately the inviscid, rotational flow field and pressure distribution about a smooth, two-dimensional airfoil with sharp leading and trailing edges in a uniform supersonic or hypersonic stream. Using the analytic form of the isentropic shock-expansion method, an analytically consistent perturbation method is developed by expanding the dependent flow variables in the exact partial differential equations in powers of the reflection coefficient for simple waves interacting with an oblique shock. Analytical solutions are obtained for the first-order corrections, including the surface pressure distribution. The zero-order shock shape and first-order pressure distribution are calculated for a family of parabolic-arc airfoils at an infinite free-stream Mach Number, as an illustrative example.

CALCULATION OF THE FLOW PAST SLENDER DELTA WINGS WITH LEADING EDGE SEPARATION. Appendix I - THE TWO-DIMENSIONAL VELOCITY FIELD OF A VORTEX SHEET IN THE SHAPE OF A CIRCULAR ARC, WITH STRENGTH DEPENDENT ON THREE PARAMETERS. Appendix II - ALGEBRAIC EXPRESSION OF THE CONDITIONS ON THE ARC. Appendix III - EXPRESSIONS FOR THE FLOW QUANTITIES ON THE WING. K. W. Mangler and J. H. B. Smith. Gt. Brit., RAE Rep. Aero. 2593, May, 1957. 49 pp. Analysis of flow past a sharp leading edge of a delta wing. At incidence this flow separates along the edge and a vortex layer extends from the edge and rolls up to form a "core" (a region of high vorticity). A potential flow model is constructed in which the layer is replaced by a vortex sheet which is rolled up into a spiral in the region of the "core". The problem is reduced to a two-dimensional one by assuming a conical field and using slender-wing theory. Results are obtained for the pressure distribution, chord loading, and normal force coefficient as functions of the ratio of the incidence to the apex angle.

THE MINIMIZATION OF WAVE DRAG FOR WINGS AND BODIES WITH GIVEN BASE AREA OR VOLUME. Max. A. Heaslet. US, NACA TN 3289, July, 1957. 28 pp. Theoretical investigation for thin, aerodynamic shapes carrying no lift. A general expression is derived for minimum drag which assumes the most elementary form possible while retaining the relevant parameters and being dimensionally correct. Ward's expression for drag in thin, lifting bodies is used as a starting point for the analysis which concludes with examples concerning the construction, from the known conditions on the control surface, of minimum-drag bodies of revolution. It is shown that the inversions of the integral equations are easily carried out in these special cases.

O NESUSHCHIKH SVOISTVAKH I INDUKTIVNOM SOPROTIVLENII SISTEMY KRYLO-FIUSELAZH. A. A. Nikol'skii. Prikl. Mat. i Mekh., Mar.-Apr., 1957, pp. 189-194. In Russian. Development of a method to calculate the total lift and drag of a wing-body combination at small angles of attack. The calculation is based on a given circulation distribution along the wing span and on the fact that the pressure distribution of the fuselage is unknown.

## AEROELASTICITY

FLUTTER OF T-TAILS WITH DIHEDRAL. R. L. Goldman. Martin Rep. ER 8205, July 12, 1957. 58 pp. Investigation in a low-speed wind tunnel of the flutter characteristics of various T-tail configurations to determine how horizontal stabilizer dihedral is affected by fin sweep, hull stiffness, fore and aft position of the stabilizer, and fin elastic-axis position. Results indicate that both negative and positive dihedral decrease flutter speed. Fin sweep is beneficial in some cases, being dependent on degree of hull freedom and dihedral angle. Moving the elastic axis from 40% chord to 60% chord reduces the flutter speed. Moving the stabilizer away, either fore or aft, from the vertical through the intersection of the fin elastic axis and the hull is always beneficial. Introduction of both degrees of freedom reduces the flutter speeds by between 10% and 20%.

ANALYTICAL METHODS FOR DETERMINING SPECIFIC DAMPING ENERGY CONSIDERING STRESS DISTRIBUTION. E. R. Podnieks and B. J. Lazan. USAF WADC TR 56-44 [AD 130777], June, 1957. 36 pp. 17 refs. Discussion of various energy and energy ratio units for expressing the damping properties. Specific damping energy (in.-lb./cu. in./cycle) is proposed as the most useful unit for comparing materials and performing engineering calculations. Analytical methods are presented for converting the total or average energy of a specimen to its specific damping. The role of the volume-stress function in this analysis is discussed and specific cases are illustrated. Data on the dimensionless damping and strain energy integrals are included for a range of conditions to facilitate data conversion.

FATIGUE CHARACTERISTICS OF A RIVETED 24 S-T ALUMINIUM ALLOY WING. I - TESTING TECHNIQUES. J. L. Kepert, C. A. Patching, and J. G. Robertson. Australia, ARL Rep. SM. 246, Oct., 1956. 48 pp. 17 refs. Description of two testing techniques used for the static and fatigue testing of Mustang P-51D wings. A hydraulic loading rig is used for both the static and the high alternating load tests, while for the lower alternating load tests, in which the life exceeds 80,000 cycles, a resonant-vibration rig is used in order to reduce the time of testing. Details of the design and calibration of these rigs are given, together with results indicating that the methods of testing do not influence the fatigue life of the structure.

## AIRPLANE PERFORMANCE

THE INFLUENCE OF DRAG CHARACTERISTICS ON THE CHOICE OF LANDING APPROACH SPEEDS. D. Lean and R. Eaton. (NATO AGARD Flight Test Panel, London, May, 1957.) Gt. Brit., RAE TN Aero. 2503, Apr., 1957. 25 pp. Theo-

retical study of the lift and drag characteristics of 19 jet aircraft which have minimum comfortable approach speeds that are fairly well established. Limiting values of speed stability are proposed for the three types of landing approach used for carrier, airfield, and instrument landings. The speeds corresponding to these stability levels are in fair agreement with those actually used, even for aircraft whose approach speeds are not primarily limited to drag effects. Results indicate that drag effects must be taken into account in estimating approach airspeeds, and that this process materially improves the prediction of approach speeds for the latest types of aircraft.

## AVIATION MEDICINE

DESCRIPTION AND PREDICTION OF HUMAN RESPONSE TO AIRCRAFT THERMAL ENVIRONMENTS. C. L. Taylor. (ASME Av. Div. Conf., Los Angeles, Mar. 14--16, 1956, Paper 56-AV-3.) Trans. ASME, July, 1957, pp. 1,024-1,028. Discussion of the physiological and biophysical basis of human response to high environmental temperatures. The state of the adaptation, whether compensated or noncompensated, is graphically displayed. Depending upon the clothing worn and the conditions of altitude, humidity, etc., the upper margin of the compensable zone is about 110° F. A prediction chart is shown for the use of designers, which permits a rapid calculation of tolerance and performance times for a wide range of environment and clothing conditions.

## COMPUTERS

A DATA ASSIMILATOR FOR A REAL-TIME MISSILE-PERFORMANCE ANALYSIS SYSTEM. USAF HADC TR 57-3 [AD 113039], June, 1957. 113 pp. Philosophy and design of a Data Assimilator for a real-time computing system. The Assimilator is essentially a magnetic-core memory which becomes an integral part of an electronic digital-computing system. This core memory has an additional built-in intelligence which mechanizes data input and output, eliminating unnecessary data handling, thus allowing essential computation to proceed without interruption.

## ELECTRONICS

HANDBOOK OF PIEZOELECTRIC CRYSTALS FOR RADIO EQUIPMENT DESIGNERS. John P. Buchanan. USAF WADC TR 56-156 [AD 110448], Oct., 1956. 692 pp. 928 refs. Comprehensive manual directed toward the design of oscillator circuits having optimum operating conditions when employing Military Standard crystal units. Includes a survey of the development of the art; descriptions and characteristics of all crystal elements and mounting methods for commercial applications; detailed study of the equivalent circuit characteristics of crystal units; analyses of basic piezoelectric oscillator principles and of the effects of changes in various circuit parameters; analyses and recommended design procedures for all types of piezoelectric oscillators used in USAF equipment; schematic diagrams and tables giving actual circuit parameters of all available unclassified piezoelectric oscillators now being used in USAF equipment; and discussion of crystal ovens with description of those currently available for use with Military Standard crystal units.

CONTRIBUTIONS TO THE THEORY OF NON-IDEAL WAVEGUIDES. Lin Wei-guan. Sci. Rec., Apr., 1957, pp. 27-32. Extension of results obtained from the theory of nonideal guides to include the case of imperfect conductivity on only part of the guide walls of any form of guide cross section, and that of departure from the ideal geometrical cross section. The extension is accomplished by applying the Lorentz theorem to a short section of a perturbed guide. Two forms of perturbation are considered.

## FLIGHT OPERATING PROBLEMS

CALCULATED EFFECT OF SOME AIRPLANE HANDLING TECHNIQUES ON THE GROUND-RUN DISTANCE IN LANDING ON SLIPPERY RUNWAYS. J. A. Zalovcik. US, NACA TN 4058, July, 1957. 30 pp. Analysis, based on simplifying assumptions, to determine the effect on the ground-run distance of maintaining a nose-high attitude instead of a three-point attitude in landings of several types of jet airplanes on slippery runways. The airplanes considered are a swept-wing transport and unswept-, swept-, and delta-wing fighters. The effect of such factors as speed, braking efectiveness, and residual thrust on the difference in ground-run distance with the two handling techniques is considered. Includes some computations to indicate the effect of instantaneous flap retraction.

## INSTRUMENTS

TIME CONSTANTS AND FREQUENCY RESPONSE OF COATED HOT WIRES USED AS TURBULENCE-SENSING ELEMENTS. Appendix - PROPERTIES OF BESSEL FUNCTIONS AND CYLINDER FUNCTIONS. Avis Borden. US, Navy Dept., David Taylor Model Basin, Rep. 952, June, 1957. 50 pp. Analysis of the unsteady heat flow through a solid cylindrical wire containing heat sources and a coating in the form of a cylindrical shell. The differential equations are linearized and the solutions are found by the method of Laplace transforms. The response of a constant-current coated wire is obtained for two step-like starting conditions: (1) a change in convective cooling and (2) a change in power or current input. The response of a constant-temperature coated wire is obtained for a step-like change in convective cooling. An equivalent time constant is computed for each of the three cases, and the frequency responses of the wire to sinusoidal initiating disturbances are derived in each case by applying Duhamel's theorem. Bare wire responses are obtained by letting the coating thickness shrink to zero.

CHARACTERISTICS OF THE TECHNIQUE OF AERODYNAMIC INVESTIGATION BY MEANS OF SERIES OF ELECTRIC SPARKS. J. Herzog, J. R. Weske, Y. Y. Chen, and Yoichi Saheki. U. Md. Inst. Fluid Dynamics & Appl. Math. TN BN 105

(AFOSR TN 57-359) [AD 132432], July, 1957. 50 pp. Presentation of the basic characteristics and limitations of electric-spark technique when used as a tool for aerodynamic investigation, as established by theoretical studies and by corresponding experiments and calibration tests. A series of wake traverses are taken at high subsonic Mach Numbers downstream of an airfoil. They show that wake profiles can be repeated with accuracy, provided the flow is steady. Successive spark photographs also give an insight into nonsteady flow phenomena which are found to increase in frequency of occurrence and prominence as sonic velocity is approached.

## MATERIALS

TENSION AND TORSION PROPERTIES OF SOME METALS UNDER REPEATED DYNAMIC LOADING (IMPACT). D. B. C. Taylor and A. Z. Tadros. IME Proc., No. 33, 1956, pp. 1,039 - 1,054. Description of two machines for testing metals to fracture. These machines are of the "falling-weight" type - the yield stress (or yield torque) being measured electronically and the total extension (or total twist) during a particular loading cycle being limited to any desired value. A series of tests in both dynamic tension and dynamic torsion, using solid cylindrical bar specimens of 3/8-in. diam., is carried out on a medium-carbon steel, a mild steel, and a silico-manganese steel, as well as on two aluminum alloys.

### Metals & Alloys, Nonferrous

SOME OBSERVATIONS ON STRESS-CORROSION CRACKING OF SINGLE CRYSTALS OF AZ61X MAGNESIUM ALLOY. F. Meller and M. Metzger. US, NACA TN 4019, July, 1957. 23 pp. 11 refs. Exploratory tests conducted in distilled water, in 0.5 and 1% hydrofluoric acid, and in salt-chromate solution consisting of 35 grams of sodium chloride and 20 grams of potassium chromate per liter. The path chosen by the crack is attributed to mechanical rather than electromechanical factors and the possible importance of prior deformation is pointed out.

## MATHEMATICS

APPLICATION OF THE THEORY OF LINEAR OPERATORS IN HILBERT SPACE TO POTENTIAL THEORY. E. J. Specht and H. T. Jones. Emmanuel Missionary Coll., Dept. Math. Rep. (AFOSR TN 57-306) [AD 132377], June, 1957. 46 pp. 14 refs. Historical review and statement of the problem; discussion and proof of the properties of the kernel K; and introduction and analysis of the properties of the Hilbert space and the operator, with expansions in terms of characteristic functions.

COMMUTATORS ON A HILBERT SPACE. I - COMMUTATORS AND ABSOLUTELY CONTINUOUS OPERATORS. II - ON SQUARE ROOTS OF NORMAL OPERATORS. III - ON SEMI-NORMAL OPERATORS. C. R. Putnam. Purdue U., Dept. Math., TN 1, 2, 3 (AFOSR TN 56-457; 56-479; 57-89) [AD 97073; 97363; 120437], July, 1957. 17, 3, 5 pp. 21 refs. I - Presentation of general theorems on commutator C and the associated $W_C$, and of applications of these results - in particular, to Toeplitz, Hankel, and Jacobi matrices. II - Proof of two theorems relating to bounded transformations on a Hilbert space of elements x. III - Analysis of the spectrum of a semi-normal operator and of the associated self-adjoint operators.

RESPONSE FUNCTIONS OF LINEAR SYSTEMS WITH CONSTANT COEFFICIENTS HAVING ONE DEGREE OF FREEDOM. A. W. Babister. Quart. J. Mech. & Appl. Math., Aug., 1957, pp. 360-368. 10 refs. Study of the transient response for a system satisfying linear differential equations with constant coefficients. It is shown that the response due to (1) a step function disturbance, (2) an initial impulse, and (3) a constant velocity input can be simply related to the response in the free motion.

OB USLOVIIAKH, OPREDELIAIUSHCHIKH OB'EKTY AFFINNOI SVIAZANNOSTI PROSTRANSTVA RIMANA. M. A. Ulanovskii. AN SSSR Dokl., Mar. 21, 1957, pp. 507, 508. In Russian. Derivation of conditions defining the objects of affine connectivity in Riemann space.

RESHENIE ZADACHI KOSHI I KRAEVOI ZADACHI DLIA NELINEINYKH URAVNENII V KLASSE RAZRYVNYKH FUNKTSII. O. A. Oleinik and N. D. Vvedenskaia. AN SSSR Dokl., Mar. 21, 1957, pp. 503-506. In Russian. Development of the solution of Cauchy problem and boundary-value problem for nonlinear equations in the class of discontinuous functions.

FUNCTION RINGS AND RIEMANN SURFACES. John Wermer. Inst. Advanced Study, Princeton, N. J. (AFOSR TN 57-207) [AD 126504], May, 1957. 42 pp. Consideration of a restricted class of subalgebras of C (the Banach algebra of all continuous complex-valued functions on the unit circle) in order to classify, as far as possible, the closed subalgebras of C which contain the constant 1 and which separate points on the circle. It appears that rings of analytic functions on certain Reimann surfaces play a central part in this classification.

QUASI-OPEN MAPPINGS. G. T. Whyburn. Va. U., Dept. Math. TN 1 (AFOSR TN 57-395) [AD 132470], July, 1957. 11 pp. Presentation of a straight-forward characterization of quasi-open mappings from one plane into another, in terms of the minimum modulus property which is, in turn, based on a known characterization of such mappings, taking into account their action on elementary plane regions; establishment of a general mapping result; and determination of the known result - as one of several consequences of the latter mapping result - to the effect that, in a very general setting, the quasi-open mappings form a closed class under uniform convergence.

FINITE DIFFERENCE METHODS FOR BOUNDARY VALUE PROBLEMS OF PARTIAL ELLIPTIC DIFFERENTIAL EQUATIONS AND CURVED BOUNDARIES. Werner Uhlmann. USAF OSR TR 57-46 [AD 132431], Mar., 1957. 129 pp. Derivation of finite equations for the first, second, and third boundary-value problems of the differential equa-

tion $\Delta u (x, y) = (x, y, u)$ and for the first boundary-value problem of the differential equation $\Delta u (x, y, z) = r(x, y, z, u)$, in particular, for computing points close to the boundary for curved boundaries. All formulas are tailored for quadratic grids, and numerical examples are given to illustrate the methods, which are shown to be more accurate than previous procedures and to involve only a slight increase in the amount of work required.

ON HOLDER CONTINUITY AND NON-LINEAR ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS. Philip Hartman. Johns Hopkins U., Dept. Math. TR 5 (AFOSR TN 57-175) [AD 126470], Apr., 1957. 13 pp. Estimates for the degree of continuity of mappings $(x, y) \rightarrow (p, q)$ subject to certain inequalities, and application of the results to the question of Hölder continuity of second-order derivatives of a solution to a second-order, elliptic, partial differential equation in two independent variables. In particular, a crude form of Hopf's interior estimates (for the case of two independent variables) results very simply, without the use of potential theory.

## MISSILES

GENERALIZED VARIATIONAL APPROACH TO THE OPTIMUM THRUST PROGRAMMING FOR THE VERTICAL FLIGHT OF A ROCKET. I - NECESSARY CONDITIONS FOR THE EXTREMUM. Angelo Miele. Purdue U., Sch. Aero. Eng. Rep. A-57-1 (AFOSR TN 57-1) [AD 126467], Mar., 1957. 47 pp. 11 refs. Analysis to determine the burning program which minimizes an arbitrary function of the final values of time, mass, altitude, and velocity. It is shown by calculus of variations that the totality of external arcs is composed of zero thrust subarcs to be flown with maximum engine output and variable-thrust subarcs. Cloud-form solutions are developed for three particular cases: flight in vacuum, flight in uniform atmosphere, and flight in an isothermal atmosphere. Particular problems, such as maximum increase in altitude, minimum propellant consumption, and maximum velocity increase are treated; and methods for constructing external paths are supplied under different types of boundary conditions.

OB USTOICHIVOSTI VRASHCHATEL'NYKH DVIZHENII TVERDOGO TELA, POLOST' KOTOROGO NAPOLNENA IDEAL'NOI ZHIDKOST'IU. N. G. Chetaev. Prikl. Mat. i Mekh., Mar.-Apr., 1957, pp. 157-168. In Russian. Study of the stability of rotating motion of a solid body filled with liquid. An exact solution can be obtained, based on the assumption of an ideal and incompressible fluid and on the concept that it fills the cavity completely and contains no bubbles.

## NAVIGATION

### Electronic Aids

PROBLEMS IN DOPPLER NAVIGATION. F. T. Wimberley and C. L. Crowell. (IAS Natl. Summer Meeting, Los Angeles, June 17-20, 1957, Paper.) Aero. Eng. Rev., Oct., 1957, pp. 48-53. Discussion reviewing the physics of the Doppler principle and the Doppler effect as applied to radar navigation. Consideration is given to the application of Doppler information to the aircraft navigation problem; to techniques for Doppler navigation; and to problems and errors associated with the system, in terms of problems unique to particular aircraft types, sea flow, microwave frequency, antenna considerations, signal fluctuations, and earth-reference and navigation-correction factors.

## PHYSICS

EQUIVALENCE RELATIONS IN DIFFRACTION THEORY. S. N. Karp and W. E. Williams. Cambridge Philos. Soc. Proc., July, 1957, pp. 683-690. USAF-supported analysis to establish certain equivalence relationships between different problems occurring in diffraction theory. The method used is essentially Schwarz's principle of analytic continuation by reflection across a straight boundary. An explicit solution is also obtained by this method for a plane wave normally incident on a T-shaped structure.

MOTION OF A GAS DUE TO THE EFFECT OF A BRIEF IMPULSE. A. I. Shukov and Ia. M. Kazhdan. Sov. Phys. - Acous., No. 4, 1957, pp. 375-381. Translation. Presentation of further refinements of the problem involved in integrating autosimulation equations in the determination of the effect of a shock on a cold gas. Analytical results illustrate the manner in which the gas motion under consideration acquires an autosimulating mode.

## POWER PLANTS

INJECTION AND COMBUSTION OF LIQUID FUELS. A. A. Putnam, F. Benington, H. Einbinder, H. R. Hazard, J. D. Kettelle, Jr., A. Levy, C. C. Miesse, J. M. Pilcher, R. E. Thomas, A. E. Weller, and B. A. Landry. USAF WADC TR 56-344 [AD 118142], Mar., 1957. 752 pp. Review of material in the unclassified literature relating directly to the fundamental physical phenomena involved in steady-flow processes in high-intensity combustors. To systematize the presentation, the report is divided into six parts, as follows: I. Atomization of Liquid Fuels, II. Ballistics of Droplets, III. Evaporation of Droplets, IV. Fluid Dynamics, V. Homogeneous Combustion, and VI. Heterogeneous Combustion.

### Jet & Turbine

REGELUNGSGRUNDLAGEN FUR FLUGZEUG-STRAHLTURBINEN. Leo Beck. ZFW, July, 1957, pp. 198-204. 11 refs. In German. Discussion of the fundamental laws for the control of gas turbines in jet-powered aircraft, including engines with and without afterburners as well as with and without adjustable jet nozzles. The effect of the flight condition (due to the accumulated gas temperature and accumulated total pressure in the intake) on the working conditions of the engine is set apart from the actual temperature characteristics with relevant parameters.

SOME AERODYNAMIC PROBLEMS OF AIRCRAFT ENGINES. W. R. Hawthorne. J. Aero.

Sci., Oct., 1957, pp. 713-730. 67 refs. Comprehensive discussion of basic ideas in the aerodynamics of engine design including new applications of old ideas which have become important. The influence of compressibility is reviewed, and an example of choking in frictional compressible flow is presented. Three-dimensional flow through compressors and turbines is examined, and actuator-disc theory is applied to compressors. Approximate blade performances are obtained from published two-dimensional cascade tests, and all losses are assumed to occur across the actuator discs. The inviscid equations between the discs are linearized, and the equations for each row of blades solved by an iterative procedure. Secondary flow is reviewed, as are propagating stall, combustion, and flow with heat addition.

## Rocket

CU PRIVIRE LA DETERMINAREA UNOR PARAMETRI AI RACHETELOR AUXILIARE. D. Pavelescu and D. Olaru. Stud. Cerc. Mec. Aplic., Jan.-Mar., 1957, pp. 23-33. In Rumanian. Development of an experimental method for the statistical determination of some parameters of solid-propellant auxiliary rockets, i.e., thrust, pressure in the combustion chamber, combustion temperature, and velocity of gas flows through nozzles. Includes description of the mechanical-electronic measuring system used and a comparison of results to those obtained through computation.

TECHNISCHE GASE ALS ARBEITSMEDIEN FÜR RAKETENTRIEBWERKE. Eberhard Büchner. Raketentech. & Raumfahrtforsch., July, 1957, pp. 25-30. 11 refs. In German. Study of technical gases as working media for rocket propulsion units. The gas is considered to be heated by a suitable energy source to a given high temperature and pressure, expanded, and ejected at a predetermined pressure through a Laval nozzle. Includes comparisons for steam, nitrogen, air, oxygen, hydrogen, chlorine, and carbon dioxide.

FESTSTOFFTRIEBWERKE FÜR HÖCHSTE GESCHWINDIGKEITEN. J. W. Wiggins. Raketentech. & Raumfahrtforsch., July, 1957, pp. 30-34. In German. Study of analytic relations governing the velocity of a flying body. The influence of the power-plant/weight ratio at low and high speeds is discussed and the application of multi-stage rockets as well as the increase in size caused by low-performance engines and the reduction in weight of the flying body by use of high-performance solid propellants are analyzed. Includes evaluation of new alloys and insulating materials.

ÜBER EINE MÖGLICHKEIT ZUR ERHÖHUNG DER AUSSTRÖMGESCHWINDIGKEIT BEI RAKETENTRIEBWERKEN. W. Peschka. (7th Internatl. Astronautical Cong., Rome, Sept., 1956.) Astronautica Acta, Fasc. 2, 1957, pp. 100-109. In German. Evaluation of a method, similar to the film-cooling method, for overcoming extremely high gas temperatures in combustion chambers. The expansion of hydrogen is considered, assuming an equilibrium attained by dissociation. An approximation method is developed for calculating the flow of any frictionless, compressible fluid, provided that the Mach Number of the flow is given at least by two points. This method is particularly suitable for a multidimensional flow.

COMBUSTION PROCESSES IN LIQUID PROPELLANT ROCKET MOTORS. I. E. Smith and I. Glassman. Princeton U. Dept. Aero. Eng. Rep. 334-f, June, 1957. 14 pp. Experimental investigation using the new flow-type reactor to obtain results on the ethylene oxide decomposition reaction at high temperatures. The activation energy of the decomposition reaction in the 1,660°--2,000° R. range is found to be lower than that reported for the low-temperature decomposition process.

BEITRAG ZUR THEORIE DER WASSERDAMPFRAKETE. H. Bednarezyk. (7th Internatl. Astronautical Cong., Rome, Sept., 1956.) Astronautica Acta, Fasc. 2, 1957, pp. 153-176. 17 refs. In German. Derivation of design equations for a steam rocket from consideration of the appropriate thermodynamic phenomena. The following problems are treated: outflow of hot water from the boiler (connection between pressure and amount of fluid in the vessel), measures to prevent delay in boiling during nozzle expansion, the calculation of Laval states in the nozzle, the calculation of thrust, and the design of the nozzle. The purpose of the investigation is to present the equations in a form suitable for immediate application by using only standard thermodynamic quantities of state. In some cases certain equations are treated graphically with solutions given over the whole range of practical interests.

ROCKET SCALING TESTS WITH A CONSTANT RATIO OF CHEMICAL TO WAVE PROPAGATION TIMES. S. S. Penner. AMF TD 1031 TN 3 (AFOSR TM 57231) [AD 126528], Apr. 19, 1957. 12 pp. Analysis starting with a given engine configuration to show how the ratio of chemical reaction time to wave propagation time may be maintained by (a) changing only the number of injection orifices and the area of the nozzle throat; (b) changing only the injector pressure drop, the steady operating pressure, and the nozzle throat area; (c) changing only the orifice diameter, the steady operating pressure, and the nozzle throat area.

## ROTATING WING AIRCRAFT

EFFECT OF GROSS WEIGHT AND CENTER OF GRAVITY LOCATION ON DYNAMIC STABILITY OF A TANDEM ROTOR HELICOPTER IN FORWARD FLIGHT. Gilbert Chuck. USAF FTC TN 57-13 [AD 124107], June, 1957. 60 pp. Investigation involving analysis of the roots of the linear equations of motion. The equations used include estimated stability derivatives adjusted from the process of matching flight-test time histories with analog-computer solutions. Using the real parts of characteristic roots as a measure of the dynamic stability, it is found that, for increasing gross weight and aft movement of the center of gravity, the longitudinal dynamic stability deteriorates and the lat-

eral dynamic stability remains essentially at the same level.

## SPACE TRAVEL

THE CASE FOR THE LOW ACCELERATION SPACESHIP. H. F. Michielsen. Astronautica Acta, Fasc. 2, 1957, pp. 130-152. 10 refs. Analysis of the mechanics of the escape trajectories for low-acceleration propulsion. The method used involves inversion of the formulation of the problem, i.e.: a trial-and-error procedure is used to choose a probable trajectory, which is then used to compute the corresponding thrust components; if these components are economically justified in terms of fuel consumption, the trajectory is deemed feasible. The relative efficiencies of different trajectories are expressed in terms of the required characteristic velocity, defined as the total change in velocity, resulting from a considered program of rocket-system operation, as if it were performed in empty, nongravitational space. The advantages of low-acceleration propulsion, itself, are outlined.

STUDIES OF A MINIMUM ORBITAL UNMANNED SATELLITE OF THE EARTH (MOUSE). III - RADIATION EQUILIBRIUM AND TEMPERATURE. Appendix I - EVALUATION OF ALBEDO OF PLANET EARTH. Appendix II - THE CONSTRUCTION OF A NOMOGRAM. Appendix III - DETERMINATION OF THE ANGLE BETWEEN THE ORBIT OF THE SATELLITE AND THE SUN. Appendix IV - ABSORPTION OF VISIBLE RADIATION FROM THE SUN INCIDENT ON A SATELLITE ABOVE THE EARTH. D. T. Goldman and S. F. Singer. (7th Internatl. Astronautical Cong., Rome, Sept., 1956.) Astronautica Acta, Fasc. 2, 1957, pp. 110-129. 16 refs. Calculation of the equilibrium temperature based on the equality of heat input and heat output, i.e., a zero net flow of energy. Results are presented in the form of nomograms to aid in preliminary design. It is assumed that the heat conductivity within the satellite is perfect so that all portions are at the same temperature or, at least, that the skin temperature is even.

## STRUCTURES

THE APPLICATION OF A NEW STRUCTURAL INDEX TO COMPARE TITANIUM ALLOYS WITH OTHER MATERIALS IN AIRFRAME STRUCTURES. L. R. Jackson and S. A. Gordon. (ASME Av. Div. Conf., Los Angeles, Mar. 14-16, 1956, Paper 56-AV-10.) Trans. ASME, July, 1957, pp. 949-958. Comparison of the structural index developed by Needham with results of compression tests on aluminum sections at room temperature, and with similar tests on titanium-alloy angles and channels at room and elevated temperatures. It is believed that the new structural index will provide a reliable method of evaluating the elevated temperature performance of materials, such as titanium, when only the compressive stress-strain curves are available at each temperature.

### Bars & Rods

O KSZTAŁTOWANIU KRATOWNIC NA MINIMUM POTENCJAŁU PRZEZ PRZESUWANIE NIEOBCIĄŻONYCH WĘZŁÓW ŁĄCZĄCYCH TRZY PRĘTY. Andrzej Brandt, Jan Kosmowski, and Zbigniew Wasiutyński. Rozprawy Inżynierskie, No. 2, 1957, pp. 157-205. In Polish, with summaries in English and Russian. Investigation of the transformation of trusses by the displacement of a nonloaded node, with three bars, with the object of obtaining lattice systems satisfying the condition of minimum potential energy for constant material volume. An isostatic truss composed of bars of equal strength is considered. An analysis shows that displacements of a nonloaded node point, in which three members meet, cause potential energy changes in five bars only. These are bars which form two adjacent triangles.

### Beams & Columns

OPREDELENIE PEREMESHCHENII I RASCHET STATICHESKI NEOPREDELIMYKH STERZHNEVYKH SISTEM PRI IZGIBE ZA PREDELAMI UPRUGOSTI. Iu. A. Rakovshchik. AN SSSR Otd. Tekh. Nauk Izv., Apr., 1957, pp. 75-84. In Russian. Determination of displacements and calculations of statically indeterminate bar systems in the case of bending beyond the elasticity limit.

TORSION, BENDING, AND LATERAL BUCKLING OF I-BEAMS. Henrik Nylander. Acta Polytechnica, No. 5 (102), 1956. 104 pp. 24 refs. Analysis of some stability problems which are important in the design of thin-walled beams and columns made of steel or light metals, in order to consider the fundamental theories and to throw light on some previously neglected phenomena. The problems under consideration involve a spatial effect which is taken into account by deducing the equation of torsion of a beam which is subjected simultaneously to a torsional moment, bending moments, and a compressive force. The treatment is carried out formally for I-beams of monosymmetrical cross section, but it can also be generalized to include completely unsymmetrical thin-walled beams.

### Cylinders & Shells

STRESS IN A CURVED SKIN PANEL OF A PRESSURIZED FUSELAGE; AN ANALYSIS OF A PARTICULAR STRESSING CASE. J. Lockwood Taylor. Aircraft Eng., July, 1957, pp. 216-218. Solution of the problem of an initially curved circumferential skin strip which represents a section of the panel midway between frames and which is continuous over the stringers. These stringers act as sinking supports and transfer part of the internal pressure load to the frames. The remainder of the pressure load produces hoop tension in the skin strip, but the maximum total stress, including the evaluated bending in the skin at the stringer, is shown to be greater, usually, than that arising from hoop tension alone, in an unstiffened shell.

EIN BEITRAG ZUR SCHALENTHEORIE. Kemal Ozden. Istanbul U., Fen Fakült. Mecmuasi, Ser. A, July-Oct., 1956, pp. 201-238. In German. Development of a method for the calculation of displacements in an elastic shell. The obtained re-

sults are used together with the elasticity laws to determine the stresses, and the new approach characterizing this theory is outlined. Includes application of the developed method to the problem of circular plates and conical shells.

## Elasticity & Plasticity

ON THE PLASTIC THEORY OF PLATES. H. G. Hopkins. Royal Soc. (London) Proc., Ser. A, Aug. 7, 1957, pp. 153-179. 22 refs. Development of a theory for the small deformations of a thin, uniform plate under transverse load. The plate is made of nonhardening rigid-plastic material obeying the Tresca yield condition and associated flow rule. The field equations are first presented in rectangular Cartesian coordinates, and involve the stress moments and the middle surface curvature rates as the generalized stresses and strain rates. A detailed study is made of discontinuities in the field quantities. The field equations are either parabolic or elliptic for the principal plastic regimes.

SOME ASPECTS OF THE PLASTIC DESIGN OF ALUMINIUM STRUCTURES. S. K. Ghaswala. Assoc. Internatl. Ponts & Charpentes, Mem., 1956. Reprint. 23 pp. 94 refs. Review and evaluation of theories of plasticity as applicable to the design of aluminum structures. Topics on bending and torsion, inelastic instability and plate stability, compression, and frameworks are treated. A discussion on the role of plasticity as a measure of structural strength introduces ideas on the criterion of strength in terms of slip and cohesive resistance. Reference is made to combined stresses, the concept of fatigue, and the evaluation of Poisson's ratio in the plastic range.

TWO-DIMENSIONAL PROBLEMS IN THE THEORY OF PLASTICITY OF NON-HOMOGENEOUS ANISOTROPIC BODIES. Wacław Olszak, Piotr Perzyna, and Czesław Szymański. Arch. Mech. Stosowanej, No. 3, 1957, pp. 335-358. 14 refs. Derivation of equations for two-dimensional problems, assuming the general type of anisotropy and nonhomogeneity, by starting from the equations of the theory of plasticity describing the three-dimensional state in a system of curvilinear orthogonal coordinates. Generalized definitions of two-dimensional and plane states are given in the case of simultaneous existence of anisotropy and nonhomogeneity of the material. Next, after the required conditions are obtained, consideration is given to certain particular cases of anisotropy which are of practical importance. These cases include monoclinic, transverse, and cubic anisotropy.

DRY FRICTION VIBRATION DAMPING. Stefan Ziemba. Arch. Mech. Stosowanej, No. 3, 1957, pp. 275-291. Theoretical investigation of the more essential mechanical phenomena, rather than the complex physico-chemical processes, associated with dry friction. The problem is considered in relation to external friction, for the sake of clarity. The purpose of the study is to find a more regular and simple description than heretofore available for the interdependence between the resistance exerted by dissipative dry friction forces and the velocity. Equations are developed for investigating free vibrations in the first period of damping, vibrations excited by periodic forces and damped dry friction, or the case where the internal friction contains elements of dry and viscous friction.

## Plates

BENDING OF PLATING WITH WIDELY SPACED STIFFENERS. J. C. Chapman and J. E. Slatford. IME Proc., No. 37, 1956, pp. 1,101-1,109; Communications, pp. 1,110, 1,111; Author's reply, p. 1,112. Analysis of a stiffened plate in which a bending moment is applied in the place of the stiffener webs. Owing to the initial curvature there is a radial component of force which tends to deflect the plating from its initial position, and causes a redistribution of longitudinal stress and the introduction of transverse bending stress. A numerical example illustrates this effect, and an experiment is described which confirms the theoretical conclusions for an initially flat plate.

THE TRANSVERSE FLEXURE OF THIN ELASTIC PLATES SUPPORTED AT SEVERAL POINTS. W. A. Bassali. Cambridge Philos. Soc. Proc., July, 1957, pp. 728-743. 15 refs. Derivation of exact closed-form solutions for the problem of a thin, circular plate supported at several interior or boundary points and normally loaded over the area of an eccentric circle - the load being symmetrical with respect to the center of the circle, and the boundary of the plate being free. Explicit formulas are given for the deflection, the bending and twisting moments, and shearing stresses at any point of the plate. Plates in the form of the infinite plane and half plane are also considered. Analysis uses the Kolossoff and Muskhelishvili method developed for problems of plane elasticity and extended by Lechnitzky to plate problems.

ZASTOSOWANIE NIEKTÓRYCH ZNANYCH METOD PRZYBLIŻONYCH DO ROZWIĄZANIA ZAGADNIEŃ PŁYT ORTOTROPOWYCH O DUŻYCH UGIĘCIACH. Jerzy Nowiński. Rozprawy Inżynierskie, No. 2, 1957, pp. 331-354. In Polish, with summaries in English and Russian. Application of methods proposed by Prescott, Timoshenko, and Föppl to the problems concerning orthotropic plates with large deflections. A circular cylindrical orthotropic plate bent into a portion of a spherical surface, with the same deflection surface as a cylindrically orthotropic plate subject to uniform load, is considered. Also studied are a circular cylindrical orthotropic plate on a hinged support and uniformly loaded, and an elliptical rectilinear orthotropic plate uniformly loaded and resting on a hinged support.

## Sandwich Structures

SOME NOTES ON SANDWICH DESIGN FOR MINIMUM WEIGHT AS APPLIED TO AIRPLANE WINGS. J. G. Willis. Aero. Eng. Rev., Oct., 1957, pp. 44-47. Considerations affecting the preliminary design of multispar box construction

for minimum weight. A form of construction is devised that accurately maintains contour and smoothness, and that effectively uses the structural material and associated weight to meet the strength and stiffness requirements. Analytical results indicate that the present trend to higher pressures in integral wing tanks in conjunction with very thin wings will, in many cases, justify the adoption of some form of full depth core wing construction.

## Testing

RESEARCH EQUIPMENT FOR INVESTIGATION OF AIRCRAFT STRUCTURE AT ELEVATED TEMPERATURES. J. Taylor. Aircraft Eng., Aug., 1957, pp. 228-232. Discussion of heating equipment and its control during strength tests under both steady and changing temperature conditions, with a steady load applied. The heaters consist of infrared lamps and control is maintained by an analog computer coupled with an electronic control. This control has three amplifiers, one in each phase, which can control up to 50 kilowatts by varying the grid voltage. The computer calculates the heat requirement, compares it to the measured heat flow, and passes the difference along to the controller. Thus heat requirements for one moment depend upon effects of previous heating, and calculations must be made as the test proceeds.

AIRCRAFT STRUCTURAL TESTING TECHNIQUES AT ELEVATED TEMPERATURES. R. C. Brouns and R. B. Baird. (ASME Av. Div. Conf., Los Angeles, Mar. 14-16, 1956, Paper 56-AV-15.) Trans. ASME, July, 1957, pp. 1,005-1,013. 18 refs. Discussion of the requirements for an elevated-temperature test facility, established on the basis of the need for simultaneous testing and loading of an aircraft structure. Heating devices such as heating blankets, strip heaters, film heaters, induction coils, radiant heating coils, and infrared lamps are examined in relation to methods of attaching loads. Complications caused by simultaneous heating and loading are illustrated by a discussion of two structural tests performed at the Wright Air Development Center. A description is also given for an electronic computer developed to program the aerodynamic heating of the structure.

EXPERIMENTAL METHODS IN KINETIC HEAT TESTS. W. H. Horton. Aircraft Eng., Aug., 1957, pp. 232-240. 13 refs. Discussion of the development of necessary components of a closed-loop analog kinetic-heat simulator. The required components are the following: a high-intensity output, rapid-response infra-red heater; an adequate reflector system for directing the radiant energy to the position required; a matt black surface finish to achieve the necessary economy of power; a practical technique for surface temperature measurement; a system of radiation detection; an appropriate computer network; and the voltage regulator system. The necessary equipment is described and evaluated for such a system.

## Thermal Stress

OPTIMUM STRESSES OF STRUCTURAL ELEMENTS AT ELEVATED TEMPERATURES. Arthur Schnitt, M. A. Brull, and H. S. Wolko. (ASME Av. Div. Conf., Los Angeles, Mar. 14-16, 1956, Paper 56-AV-11.) Trans. ASME, July, 1957, pp. 959-966. 15 refs. WADC-sponsored method by which optimum-stress curves for a given material at any temperature may be calculated from the room-temperature optimum-stress curves for a different material. The only data required to perform this transformation are stress-strain curves of both materials. As examples, optimum-stress envelopes are obtained for wide columns and multi-web beams over a wide range of temperatures. An appropriate procedure is developed for the determination of maximum life when creep is significant. The method is then extended to permit comparison of unprotected structures with insulated and cooled structures on the basis of minimum weight-strength and as a function of temperature and exposure time.

THE PRINCIPLE OF STATIONARY FREE ENERGY IN THE THERMOELASTIC ANALYSIS OF THIN-WALLED TUBES. Jerzy Nowiński. Arch. Mech. Stosowanej, No. 3, 1957, pp. 359-368. Derivation of a solution of the thermoelastic problem by direct establishment of differential and integral conditions of equilibrium.

APPROXIMATE ANALYSIS OF EFFECTS OF LARGE DEFLECTIONS AND INITIAL TWIST ON TORSIONAL STIFFNESS OF A CANTILEVER PLATE SUBJECTED TO THERMAL STRESSES. Appendix A - DISCUSSION OF MODAL FUNCTIONS USED IN THE ANALYSIS. Appendix B - EVALUATION OF INTEGRALS AND RELATED FUNCTIONS. R. R. Heldenfels and L. F. Vosteen. US, NACA TN 4067, Aug., 1957. 36 pp. Solution satisfying the von Kármán large-deflection equations by means of a variational principle. The results show that initial twist and applied moments can have significant effects on the changes in stiffness produced by nonuniform heating, particularly in the region of the buckling temperature difference.

SOME STRUCTURAL PENALTIES ASSOCIATED WITH THERMAL FLIGHT. J. W. Mar and L. A. Schmit. (ASME Av. Div. Conf., Los Angeles, Mar. 14-16, 1956, Paper 56-AV-9.) Trans. ASME, July, 1957, pp. 990-1,004. Investigation of the short-time static strength of a structure as it is subjected to the combined action of maneuvering loads and internal heat flow. Various flight missions of extremely transient character are formulated. The aircraft structure is represented by various box beams, and these flow, figuratively speaking, through various missions. Approximations are made to simplify the heat-transfer equations, and transient temperature and stress distributions are obtained. Aluminum 2024S-T, titanium Ti-150A, and Inconel X are the materials considered. With these data the structural penalties which accompany thermal flight are assessed.

DESIGN CRITERIA FOR HEATED AIRCRAFT STRUCTURES. Robert Goldin. (ASME Av. Div. Conf., Los Angeles, Mar. 14-16, 1956, Paper 56-AV-14.) Trans. ASME, July, 1957, pp. 980-985. Discussion of engineering conditions which constitute structural criteria. It is recalled that in current aircraft-design practice, primary "limit conditions" are arbitrarily formulated on the basis of not combining two or more maximum severity conditions. Aerodynamic heating superimposes maximum temperature, temperature gradients, and creep life - all as additional parameters which severely influence design. Proposals relating to safety factors, creation of limit load-and-temperature condition combinations, and the introduction of creep life are presented, together with illustrative examples of criteria for two types of aircraft.

A THREE-DIMENSIONAL THERMOELASTIC PROBLEM WITH DISCONTINUOUS BOUNDARY CONDITIONS. Witold Nowacki. Arch. Mech. Stosowanej, No. 3, 1957, pp. 319-324. Analysis to determine the stress in an elastic semi-space in a steady temperature field, under the following conditions: the plane $z = 0$ bounding the elastic semi-space is kept at constant temperature inside the circle of radius $r = a$; the exterior of that circle is thermally insulated; and the semi-space is assumed to be free from stress at the $z = 0$ plane and at infinity.

RECENT RESEARCH ON THE CREEP OF AIRFRAME COMPONENTS. Eldon E. Mathauser, Avraham Berkovits, and Bland A. Stein. US, NACA TN 4014, July, 1957. 12 pp. Summary giving experimental lifetime data from creep tests of stainless-steel plates and aluminum-alloy unstiffened circular cylinders, and the results of a study to determine the magnitude of creep strains that produce significant structural deformations. The former data are compared with results predicted from isochronous stress-strain curves, and a comparison of structural weight determined from assumed strength and from creep criteria, to establish temperature ranges in which creep is expected to influence structural design for various materials.

A DYNAMICAL PROBLEM OF THERMOELASTICITY. Witold Nowacki. Arch. Mech. Stosowanej, No. 3, 1957, pp. 325-334. Analysis of the problem in which an instantaneous source of heat acts in an infinite elastic space of initial temperature $T = 0$. The action of this source will result in a temperature and stress field in the elastic space. Assuming that the thermal and elastic properties of the medium are constants, independent of the coordinates and the temperature, the action of the instantaneous source will provoke dynamic effects. In the displacement equations of the theory of elasticity the inertia terms are taken into account. The problem is characterized by spherical symmetry, the temperature and stress being dependent on the distance R from the source and the time t.

EFFECT OF TRANSIENT HEATING ON VIBRATION FREQUENCIES OF SOME SIMPLE WING STRUCTURES. Louis F. Vosteen, Robert R. McWithey, and Robert G. Thomson. US, NACA TN 4054, June, 1957. 10 pp. Investigation of some of the effects caused by nonuniform temperature distributions associated with transient heating in the effective stiffness of wing structures. Tests are conducted on a uniform plate, solid double-wedge section, and circular-arc multiweb wing section. Changes in stiffness are determined by measuring the changes in natural frequency of vibration during transient heating. A resonance-following system is developed to keep the model vibrating at its natural frequency. Some of the data are compared with theoretical calculations and show that at temperature differences near those required for thermal buckling, distortions have a marked effect on the frequency.

## Weight Analysis & Control

WEIGHT-EFFICIENCY ANALYSIS OF THIN-WING CONSTRUCTION. R. A. Anderson. (ASME Av. Div. Conf., Los Angeles, Mar. 14-16, 1956, Paper 56-AV-13.) Trans. ASME, July, 1957, pp. 974-979. Review of information on the weight efficiency of multiweb thin-wing construction. The effects of corrugated-web systems and steel-sandwich cover skins on weight efficiency are analyzed, and simple criteria are given for estimating the effect on weight of changes in the material properties of the structure.

## Wings

THE EXPERIMENTS AND ANALYSIS ON THE ELASTIC PROPERTIES OF THE SWEPT-BACK WING PLATE. Tsuyoshi Hayashi and Takashi Akasaka. Japan Soc. Aero. Eng. J., July, 1957, pp. 4-11. In Japanese. Theoretical and experimental investigation of the elastic properties of a $30^{\circ}$ swept-back parallelogram wing plate with constant thickness, taking into account two loading cases - simple torsion and concentrated loads.

EFFECTS OF AIRPLANE FLEXIBILITY ON WING BENDING STRAINS IN ROUGH AIR. Appendix - EFFECTS OF SPANWISE VARIATIONS IN TURBULENCE ON MEASURED FREQUENCY-RESPONSE FUNCTIONS. T. L. Coleman, Harry Press, and C. C. Shufflebarger. US, NACA TN 4055, July, 1957. 22 pp. Results of Boeing B-29 and B-47 A flight tests in rough air, presented as frequency-response functions of the bending strains at various spanwise wing stations to gust disturbances. Data for the B-29 are compared with analytical results, and it is shown that, for this airplane, the effects of first and second symmetrical bending modes yield moderate strain amplifications in rough air all along the air span. Calculations involving one, or preferably two, structural modes appear to yield reliable estimates of the flexibility effects on the strains. For the B-47 airplane, the dynamic amplifications appear to be quite large, particularly in the midspan region, but these amplifications are partially balanced by large and favorable aeroelastic effects associated with the swept-wing airplane.

## THERMODYNAMICS

### Combustion

COMBUSTION RESEARCHES AND REVIEWS 1957. NATO AGARDograph 15, 1957. 204 pp. 248 refs. Contents: STATIONARY FLAMES AT PRESSURES ABOVE ONE ATMOSPHERE, G. A. McD. Cummings. HYDROGEN-HALOGEN FLAMES, R. C. Anderson. FLAME-SPREADING CHARACTERISTICS IN COMBUSTION, N. R. L. Maccallum. ETUDE DE LA FLAMME DES MELANGES AIR-KEROSENE (Flame Studies of Air-Kerosene Mixtures), J. Rappeneau. BUBBLE-POINTS, FLAMMABILITY LIMITS AND FLASH-POINTS OF PETROLEUM PRODUCTS, B. P. Mullins. THEORETICAL ANALYSIS OF REACTION RATE CONTROLLED SYSTEMS. I, M. V. Herbert. REMARQUES SUR LES PULSOREACTEURS (Remarks on Pulse-Jets), J. Ducarme. QUELQUES RESULTATS OBTENUS A LA S.N.E.C.M.A. DANS L'ETUDE DES PULSOREACTEURS (On Some Results Obtained by SNECMA from the Study of Pulse-Jets), J. Bertin and B. Salmon. AN INTRODUCTION TO THE USE OF THE SHOCK TUBE FOR THE DETERMINATION OF PHYSICO-CHEMICAL PARAMETERS, S. S. Penner, F. Harshbarger, and V. Vali. AN OUTLINE OF A METHOD FOR PREPARING ENTHALPY CHARTS FOR DISSOCIATING GAS MIXTURES IN THE TEMPERATURE RANGE 600° TO 4,000°K, O. Lutz.

PULVERISATION ET COMBUSTION DANS UN ECOULEMENT D'AIR A GRANDE VITESSE. G. Chevalerias and R. Kling. La Recherche Aéronautique, May-June, 1957, pp. 9-15. 19 refs. In French. Study of the spraying and combustion of a liquid propellant in a high-speed air flow, such as is encountered in the reheat chamber of a turbojet or a ramjet. The process that takes place between the injection of fuel and the complete combustion is analyzed and the apparatus used in these tests is described. The use of ultra-rapid microphotography permits the determination of droplet distribution and the influence on this distribution of certain parameters (airspeed, injector distance).

## VTOL & STOL

FLIGHT-TEST INVESTIGATION ON THE LANGLEY CONTROL-LINE FACILITY OF A MODEL OF A PROPELLER-DRIVEN TAIL-SITTER-TYPE VERTICAL-TAKE-OFF AIRPLANE WITH DELTA WING DURING RAPID TRANSITIONS. R. O. Schade. US, NACA TN 4070, Aug., 1957. 19 pp. Description of the test facility and results of tests to determine longitudinal stability and control characteristics of a VTOL model during rapid transitions from hovering to forward flight and back to hovering. It is found that rapid transitions from hovering flight to forward flight can be performed fairly easily, but precise longitudinal control is necessary to perform the transitions smoothly. The transitions from forward flight to hovering flight are more difficult to perform because of the greater variation in power settings which require closer coordination of the power and pitch control.

## WATER-BORNE AIRCRAFT

AN EMPIRICAL ANALYSIS OF THE PLANING LIFT CHARACTERISTICS OF RECTANGULAR FLAT-PLATES AND WEDGES. P. Ward Brown. Gt. Brit., ARC R&M 2998, 1957. 23 pp. 10 refs. Development of empirical formulas for the lift of planing plates and wedges. The formulas are mutually compatible and cover the whole range of planing for zero and finite deadrise surfaces, including the chine-dry and chine-wet conditions. Comparison is made with experimental data over a range of trim angles from 2° to 30° and deadrise angles from 0° to 40°, and very good agreement is obtained. The analysis confirms the existence of an effective critical wetted length for all the planing surfaces studied and shows that the waverise about planing wedges is an irrelevant feature of the flow.

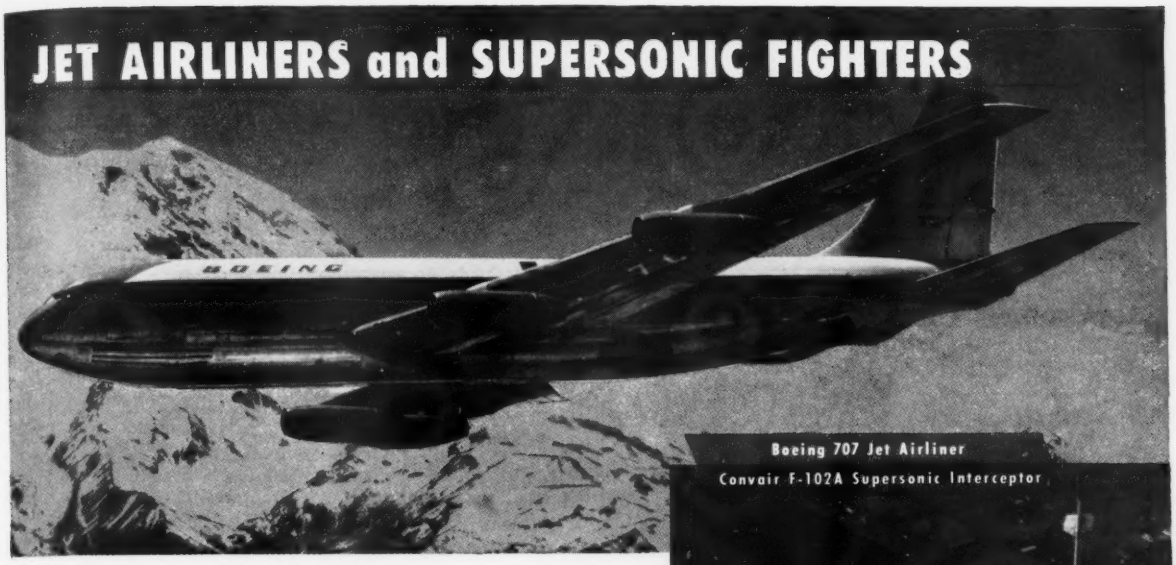
## WIND TUNNELS & RESEARCH FACILITIES

DETERMINATION OF PREFERRED METHOD OF PRODUCING AIR TEMPERATURES ENCOUNTERED IN FLIGHT BY HYPERSONIC AIRCRAFT AND MISSILES. J. M. Allen, J. F. Quirk, J. J. Ward, and D. R. Bussman. USAF AEDC TR 57-11 [AD 131407], July, 1957. 68 pp. 23 refs. Summary of the characteristics of previously considered heat-storage systems, and a detailed report on the preferred system - a single-pass storage-bed heater. Operational requirements for an air-heater system are presented, along with a discussion of high-temperature working fluids for tunnels.

AERODYNAMIC STUDIES IN THE SHOCK TUBE. Josef Rabinowicz. GALCIT Memo. 38, June 10, 1957. 111 pp. 38 refs. Evaluation of a shock tube for use in investigations. A description is given of the development of a thin platinum film-resistance thermometer, and of the heat-transfer gage and its calibration. Flow conditions in the straight section of the shock tube are calculated using recent NBS data on air properties at high temperatures. The flow conditions are also measured utilizing the heat-transfer gage and several independent experimental techniques, and good agreement is found with the equilibrium-flow calculations after an initial period of 30-50 microsec. Measurements of the heat-transfer rate at the forward stagnation point and on the circumference of a circular cylinder are reported, and compared with the theoretical calculations of Lester Lees.

LUMINESCENT GAS FLOW VISUALIZATION FOR LOW DENSITY WIND TUNNELS. W. B. Kunkel and F. C. Hurlbut. J. Appl. Phys., Aug., 1957, pp. 827-835. 27 refs. WADC-sponsored description of the successful application of afterglows to the visualization of flows in nitrogen, air, argon, and helium. Results of recent tests indicate that the range of practicability of the enriched air-glow technique extends from Mach 2 to Mach 4. The argon and helium gases are found to be useful in the Mach 1.3 - 2 range. Representative glow photographs are used to support the findings.

# JET AIRLINERS and SUPERSONIC FIGHTERS

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straight-forward computing scheme is outlined for calculating the surface velocities and pressures on any airfoil at angle of attack.

**Note on the Drag Due to Lift of Slender Wings.** D. Küchemann. *J. RAeS*, June, 1957, pp. 423, 424. Analysis which shows that camber and twist, determined by optimizing the drag due to lift and omitting leading-edge suction, may give misleading results when the lift force is obtained by linear theory.

**M-W Wings Sidestep Drawback of Sweep.** J. S. Butz, Jr. *Av. Week*, July 15, 1957, pp. 50, 51, 53, 55, 57–61 ff. Discussion introducing two wing shapes—M and W—which are being tested for use on large, heavy transports and bombers designed to cruise at supersonic speeds. Study reviews the search for an ideal wing shape to meet these requirements, the question of drag, and the problems of instability and roll in relation to the swept wing. Advantages cited for the new shapes include improvement of pitch-up and lateral stability, decrease in weight, and freedom of wing incidence from bending and torsional load effects. Disadvantages of the shapes are also discussed, along with other composite-wing proposals and German work in the field.

**Motorgondel - Flügel - Interferenz bei hohen Geschwindigkeiten (Die Flächenregel).** Otto Frenzl. *ZFW*, June, 1957, pp. 181–183. In German. Discussion of investigations on the area rule, performed in 1943 by Junkers Aircraft.

## Aeroelasticity

**Bibliography of the Material Damping Field (With Abstracts and Punched Card Codings).** L. J. Demer. *USAF WADC TR 56–180*, June, 1956. 100 pp.

**Flexural Oscillations in Composite Rods.** Vaclav Vodicka. (*ZAMM*, No. 1/2, 1957, pp. 44–51.) *Gt. Brit., RAE Lib. Transl. 667*, May, 1957. 14 pp.

**Some Secondary Effects Related to Impact Wave Forms.** J. S. Nisbet and J. N. Brennan. *ASA J.*, July, 1957, pp. 837–842. Army-sponsored analysis of changes in the shock spectrum that may arise from minor variations in the form of an applied pulse. The effects of shock-excited resonances in a machine are investigated together with methods of minimizing their effect.

**Theoretical Investigation of Flutter of Two-Dimensional Flat Panels with one Surface Exposed to Supersonic Potential Flow.** Herbert C. Nelson and Herbert J. Cunningham. *U.S., NACA Rep. 1280*, 1956. 24 pp. 20 refs. Supt. of Doc., Wash., $0.30. Application of a Rayleigh-type analysis, involving chosen modes of the panel as degrees of freedom. Includes comparison of results and of Isaacs' Criterion for the static stability of buckled panels, with a few experimental results on flat and buckled panels clamped at leading and trailing edges.

**Wind-Tunnel Flutter Tests on a Delta Wing with an All-Moving Tip Control Surface.** D. R. Gaukroger. *Gt. Brit., ARC R&M 2978*, (Oct., 1953) 1956. 17 pp. BIS, New York, $0.90. Test results which indicate that certain combinations of control-surface inertia and circuit stiffness produce

very low flutter speeds. Tip cropping is found to be beneficial.

**Atmospheric Turbulence Encountered by Hermes Aircraft.** J. R. Heath-Smith. (*Gt. Brit., RAE TN Struc. 214,* Jan., 1957.) *Gt. Brit., ARC CP 334,* 1957. 20 pp. BIS, New York, $0.64.

**The Variation of Gust Frequency with Gust Velocity and Altitude.** N. I. Bullen. (*Gt. Brit., RAE TN Struc. 216,* Oct., 1956.) *Gt. Brit., ARC CP 324,* 1957. 13 pp. 11 refs. BIS, New York, $0.54.

**Results of a Flight Investigation on Clear Air Turbulence at Low Altitude Using a Meteor Mk. 7 Aircraft.** R. M. Allan. (*Gt. Brit., RAE TN Aero. 2390,* Sept., 1955.) *Gt. Brit., ARC CP 329,* 1957. 16 pp. BIS, New York, $0.45.

**Loads Implications of Gust-Alleviation Systems.** William H. Phillips. *U.S., NACA TN 4056,* June, 1957. 11 pp. Review of factors affecting gust loads and the methods and devices which reduce these loads. Includes flight measurements of the effects of a yaw damper on the tail loads of a bomber airplane.

## Aeronautics, General

**A Special Report on the IAS National Summer Meeting; Summary of Technical Sessions.** Allen Bernhardt. *Aero. Eng. Rev.,* Sept., 1957, pp. 40–45.

**Reflections on Our First Quarter Century.** Clark B. Millikan. *Aero. Eng. Rev.,* Sept., 1957, pp. 32–35, 39.

**Canada's Expanding Exports in the Aircraft Industry.** James Montagnes. *Auto. Ind.,* July 15, 1957, pp. 48–50, 126, 127. Discussion of current and future development and Canadian production programs.

**Air Force Research and Development in Space Technology.** Thomas S. Power. *Aero. Eng. Rev.,* Sept., 1957, pp. 36–39. Discussion of the necessity for studying space, and a brief description of programs on solar radiation, cosmic radiation, space communications, space effects on terrestrial weather, effects of gravitational forces, and meteor erosion.

**The Place of the Chemical Industry in Missile Systems Planning.** Stewart A. Johnston and Herbert R. Lawrence. *CCDA Spring Meeting, French Lick, Ind., May 13, 14, 1957.* 6 pp. Discussion of contributions the chemical industry can make in the field of propellant chemistry, metallurgy, cryogenic techniques, refractory materials, and production methods.

## Air Transportation

**Measuring Field Handling and Transportation Conditions.** Donald S. Martin. *USAF WADC TR 56-464 [AD 110586],* Nov., 1956 (1957). 26 pp. Development of an instrument to measure rough handling of packages in terms of drop height. The statistical shipping plan for using the instrument and a method of relating the data obtained to container design are also discussed.

**The Comparative Economics of Jet and Propeller-Turbine Operations.** R. M. Clarkson and D. R. Newman. *Flight,* July 5, 1957, pp. 8–11. Analysis showing the advantages of pure jet aircraft over turboprops in the 500 mile and 2,500 mile stage.

## Airplane Design

**Airplane Design Implications of the Inertia Coupling Problem.** R. Richard Heppe and Leo Celniker. (*IAS 25th Annual Meeting, New York, Jan. 28–31, 1957, Preprint 723.*) *Aero. Eng. Rev.,* Sept., 1957, pp. 69–74. Abridged.

**The Starliner. III.** *Lockheed Field Serv. Dig.,* July-Aug., 1957, pp. 13–27. Discussion of the hydraulic system, landing gear and brakes, flight controls, fuel system, and the air conditioning system of the 1649A transport.

**S2F Design Sires Family of Economical Adaptations.** Russell Hawkes. *Av. Week,* July 1, 1957, pp. 46–49. Design characteristics of the Grumman TF-1 utility transport and discussion of its various missions.

**Fixed Leaf Springs Replace Rods and Springs.** *Des. News,* July 1, 1957, pp. 50, 51. Description of the use of two parallel leaf springs to measure simultaneously aileron and elevator stick loads.

**Study, High Performance Cabin Cooling Unit.** Appendix I—**Heat Exchanger Design.** Appendix II—**Theoretical Investigation of Wet Heat Exchanger.** Appendix III—**Description of Tests.** Appendix IV—**Sample Calculation-Performance of HPCC System.** Arthur P. Lane. *USAF WADC TR 54-389,* Oct., 1954 (1956). 145 pp. 27 refs. Investigation of the problems involved in designing a high-performance, air-cycle, cabin-conditioning system for jet airplanes. Performance data pertaining to bomber airplanes are used and the study leads to the selection, based on the specified operating conditions, of a regenerative bootstrap system incorporating a split regenerative heat exchanger. An analytic method is developed for determining the performance of a heat exchanger when moisture is condensed from the cooled air, and a test program is undertaken to validate the method.

**Mechanics of Tyre (1st Report, On the Fundamental Survey).** Takashi Akasaka. *J. Japan Soc. Aero. Eng.,* June, 1957, pp. 7–14. In Japanese. Theoretical and experimental investigation into the fundamental anisotropic elastic properties of a tire. Includes analysis for two boundary-condition cases of the state of the anisotropic toroidal shell under uniform inner pressure.

**Turbo-Prop Performance Analysis and Flight Planning; A Viscount Operator's Approach.** J. R. Baxter. *J. RAeS,* June, 1957, pp. 391–405; Comment and Author's reply, pp. 405, 406. Description of techniques applicable to engines of the single-spool type, such as the Dart. Includes some information on the derivation and use of the planning charts and on methods of operating for optimum economy at maximum range.

## Airports

**Heliport Capacity and Marking.** R. D. Tufford. *AHS Newsletter,* June, 1957, pp. 7, 8. Discussion leading to a suggestion for a standard marking system for visual flight rules at heliports.

## Aviation Medicine

**Subjective Thermal Comfort Zones of Ventilated Full Pressure Suit at Altitude.** Herbert R. Greider and Louis J. Santa Maria. (*Aero. Med. Assoc., 27th Annual Meeting, Chicago, Apr. 17, 1956.*) *J. Av. Med.,* June, 1957, pp. 272–276. Experimental investigation to determine the ambient temperatures characterizing the comforable, comfortably warm, and comfortably cool zones for subjects wearing the U.S. Navy suit.

**The Physiology of Pressure Suits.** H. L. Roxburgh and J. Ernsting. (*Aero. Med. Assoc., 27th Annual Meeting, Chicago, Apr. 17, 1956.*) *J. Av. Med.,* June, 1957, pp. 260–271. 13 refs.

**Effects of Mechanical Force on Living Tissue. III—A Compressed Air Catapult for High Impact Forces.** John P. Stapp and Wilbur C. Blount. (*Aero. Med. Assoc., 27th Annual Meeting, Chicago, Apr. 17, 1956.*) *J. Av. Med.,* June, 1957, pp. 281–290.

**The Stress Concept Applied to Flying.** Thaddeus J. Domanski. (*Aero. Med. Assoc., 28th Annual Meeting, Denver, May 7, 1957.*) *J. Av. Med.,* June, 1957, pp. 249–252. Discussion of fatigue data with respect to highly experienced aircrew personnel engaged in the performance of accustomed duties on flights devoid of major malfunction, accident, or near accident.

**In-Flight Hyperventilation During Jet Pilot Training.** Bruno Balke, J. Gordon Wells, and Robert T. Clark, Jr. *J. Av. Med.,* June, 1957, pp. 241–248. Spot sampling of mixed expired air in order to obtain information on the intensity of in-flight ventilation.

**Visual Contrast Thresholds for Moving Point Sources.** G. Van Den Brink and M. A. Bouman. *J. OSA,* July, 1957, pp. 612–618. 13 refs. Measurement of contrast thresholds using different exposure times, for moving point sources over a wide range of brightnesses of the adapting field with different color combinations of stimulus, as a function of the length of the covered track.

**On the Response of the Human Eye to Light Stimuli Presenting a Spatial or Temporal Gradient of Luminance.** Lucia Ronchi and G. Toraldo di Francia. *J. OSA,* July, 1957, pp. 639–642. USAF-supported discussion of the results of experiments which indicate that there is some evidence that the cone mechanism is responsible for the vision of Mach bands. It appears, however, from measurements in the peripheral retina and from electroretinographic investigation, that the rod system contributes to the sensation of higher brightness of the graded field.

**Human Tolerance to Prolonged Acceleration.** George D. Zuidema, Sanford I. Cohen, Albert J. Silverman, and Mitchell B. Riley. *USAF WADC TR 56-406 [AD 97156],* Oct., 1956 (1957). 12 pp. Evaluation using the human centrifuge.

**Relation of Threshold Criterion to the Functional Receptors of the Eye.** John L. Brown, Margaret P. Kuhns, and Helmut E. Adler. *J. OSA,* Mar., 1957, pp. 198–204. 19 refs. USAF-supported measurements using the method of constant stimuli to determine luminance thresholds for

the resolution of parallel-line grating-test patterns in the dark-adapted eye.

**On the Functional Relation Between Luminous Energy, Target Size, and Duration for Foveal Stimuli.** George F. Nolan. *J. OSA*, May, 1957, pp. 394–397. Analysis, in terms of luminous energy rather than luminance, of Graham, Bartlett, Karn, and Austin's data regarding vision.

**Auditory Adaptation.** James F. Jerger. *ASA J.*, Mar., 1957, pp. 357–363. 11 refs. USAF-supported measurement of the apparent decline in the ear's response under sustained stimulation, for pure tones over a wide range of frequencies and intensities by the median-plane-localization method.

**Factors in, Variability in, and Prediction of Regional Sweating Rates of Humans.** Iain D. Ferguson, Margaret L. Christensen, Joseph G. Kappel, and Alrick B. Hertzman. *USAF WADC TR 56-312 [AD 118055]*, Dec., 1956 (1957). 37 pp.

**Electrophysiological Evidence for Auditory Sensitization.** John R. Hughes and Walter A. Rosenblith. *ASA J.*, Feb., 1957, pp. 275–280. 23 refs. USAF-Army-Navy-supported investigation of the properties of the first neural response to tone pips.

**On the Relation Between the Intelligibility and Frequency of Occurrence of English Words.** Davis Howes. *ASA J. (USAF CRC TR 56-2) [AD 98830]*, Feb., 1957, pp. 296–302; Discussion, pp. 302–305. 23 refs.

**Modified Blender Cup for Homogenizing Small Tissue Samples.** N. Burr Furlong, Jr. *USAF WADC TN 57-16 [AD 110720]*, Jan., 1957. 6 pp. Description of a device which adapts a standard tissue-blender motor for the homogenization of tissue samples from 1 to 20 grams in weight. The homogenizer cup is airtight and encloses approximately 100 cc. of gases.

### *Human Engineering*

**Investigations of the Optimal Characteristics of Visual Light Indicator Systems.** Rosalie Noble and John Lazo. (*Aero. Med. Assoc., 28th Annual Meeting, Denver, May 7, 1957.*) *J. Av. Med.*, June, 1957, pp. 318–321. Series of experiments to determine the optimal visual characteristics, in terms of attention getting and holding, of a caution and warning system for an aircraft.

**A Program of Human Engineering Research on the Design of Aircraft Instrument Displays and Controls.** Alexander C. Williams, Jr., Marvin Adelson, and Malcolm L. Ritchie. *USAF WADC TR 56-526 [AD 110424]*, Dec., 1956. 34 pp. Discussion of a program for research on human factors in aircraft controls using three major approaches. One concerns the development of a cockpit for a particular airplane or type of airplane. Another concerns the development of principles of man-machine relations applicable to many types of aircraft. The third approach works with formal conceptual systems which have general applicability to the cockpit problems.

**Human Engineering Aspects of Radar Air-Traffic Control. IV—A Comparison of Sector and In-Line Control Procedures.** Lowell M. Schipper, John Versace, Conrad L. Kraft, and James C. McGuire. *USAF WADC TR 56-69 [AD 110528]*, Sept., 1956. 27 pp. Evaluation of two types of two-man control procedures according to safety and efficiency. Results are about equal for each system, but it appears that the sector system should be given extensive operational tests as an alternative procedure to the present in-line control.

**Design Controls: Chapter VI of the Joint Services Human Engineering Guide to Equipment Design.** Jerome H. Ely, Robert M. Thomson, and Jesse Orlansky. *USAF WADC TR 56-172 [AD 118023]*, Nov., 1956 (1957). 97 pp. 85 refs. Compilation of human engineering recommendations concerning various aspects of control selection and design.

**More Comfort for the Crews.** R. B. Crisman and C. L. Forrest. (*SAE Natl. Aero. Meeting, New York, Apr. 2–5, 1957, Preprint 107.*) *SAE J.*, July, 1957, pp. 42, 43. Abridged. Application of a sealed cabin with stored gas to provide adequate pressurization and respiration, and with an insulated and cooled type of structure to maintain desired temperature.

**Effect of Gloves on Control Operation Time.** James V. Bradley. *USAF WADC TR 56-532 [AD 110565]*, Nov., 1956 (1957). 11 pp. 14 refs. Evaluation of five types of controls operated at room temperature with the hand clothed as follows: no gloves, wool glove, and double glove. Operation time is measured in each case.

**A Broad Band Blue Lighting System for Radar Approach Control Centers: Evaluations and Refinements Based on Three Years of Operational Use.** Conrad L. Kraft. *USAF WADC TR 56-71 [AD 118090]*, Aug., 1956 (1957). 96 pp. 36 refs.

**Procedures for Including Human Engineering Factors in the Development of Weapon Systems.** Harold P. Van Cott and James W. Altman. *USAF WADC TR 56-488 [AD 97305]*, Oct., 1956 (1957). 116 pp. 32 refs. Discussion of man-machine system and the role of human engineering in their design. A design schedule suggests at what points and in what ways human engineering should be accomplished, and procedures to assess and solve human engineering problems are suggested. Human capabilities and limitations are then discussed from the point of view of the man as a system component.

## Computers

**An Algorithm for Determining Minimal Representations of a Logic Function.** Bernard Harris. *IRE Trans., EC Ser.*, June, 1957, pp. 103–108. Description of a method for constructing the minimal representations of a logic function given as a truth-table or in one of its canonical forms. The minimals achieved are either sums of products, or products of sums, such that no term contains superfluous variables and no term is superfluous.

**Dutch ATC Computer Eases Controller's Workload.** William G. Osmun. *Av. Age*, July, 1957, pp. 226–231 ff. (Also in *Flight*, July 5, 1957, pp. 23, 24.) Description of a computer in which each center can make its own decision. Fixed artificial blocks are used for separation, and symbols or call signs may be used for identification. The apparatus turns teletyped data into digital values and gives departure, airspeed, and altitude in the message.

**A Time-Sequential Tabular Analysis of Flip-Flop Logical Operation.** Gene W. Arant. *IRE Trans., EC Ser.*, June, 1957, pp. 72–74. Presentation of equation methods and time-sequential methods and a discussion of some of the advantages of the tabular method.

**Lace (The Luton Analogue Computing Engine). I.** R. J. Gomperts and D. W. Righton. *Electronic Eng.*, July, 1957, pp. 306–312. Discussion covering the requirements determining the design of the computer, the equipment incorporated into it, and proposed additional facilities.

**Dynamic Accuracy as a Design Criterion of Linear Electronic-Analog Differential Analyzers.** Amos Nathan. *IRE Trans., EC Ser.*, June, 1957, pp. 74–86. Presentation of a frequency error analysis for computing elements. The method leads to a definition of their dynamic accuracy.

**Trigonometric Resolution in Analog Computers by Means of Multiplier Elements.** R. M. Howe and E. G. Gilbert. *IRE Trans., EC Ser.*, June, 1957, pp. 86–92. Discussion of a method of generating sine and cosine functions in analog computers by means of multiplier elements and integrators.

**A New Diode Function Generator.** T. Miura, H. Amemiya, and T. Numakura. *IRE Trans., EC Ser.*, June, 1957, pp. 95–100. Description of a new function generator in which functions are generated by connecting independent line segments. Accordingly, the slope of each segment is given independently and also quantitatively, and it is possible to approximate any described function without recourse to an oscilloscope for inspection.

**An Electronic Analog Multiplier.** David C. Kalbfell. *IRE Trans., EC Ser.*, June, 1957, pp. 100–102. Description of a multiplier using the variable pulse area principle, but employing phase-sensitive circuitry to operate naturally in all four quadrants without bias voltages.

**Computing Techniques for the Sampling Parametric Computer.** C. J. Hirsch and F. C. Hallden. *IRE Trans., EC Ser.*, June, 1957, pp. 108–119. Description of methods suitable for an electronic analog computer using exponential discharge to simulate the logarithmic scales of the slide rule.

## Education & Training

**Air Force Institute of Technology.** Dean C. Strother. *Sperryscope*, 2nd Quarter, 1957, pp. 2–5. Description of a post-graduate technical school for officers, which includes four major educational programs: the Resident Instruction Division, the Civilian Institutions Division, the Installations Engineering School, and the Advanced Logistics Education and Research Project.

**Effects of Practice with and Without Correction upon Discrimination Learning Under Absolute Conditions.** Charles W. Eriksen. *USAF WADC TR 57-71 [AD 118027]*, Feb., 1957. 16 pp. 11 refs.

**Transfer and Retroaction Effects of "Association Reversal" and "Familiarization" Training in Trouble Shooting.** Lawrence M. Stolurow, Thomas F. Hodgson, and John Silva. *USAF PTRC RR TN 57-46 [AD 126376]*, Apr., 1957. 23 pp. 17 refs. Study of the effect which different amounts, types, and sequences of training and Air Force job experience has upon ability to recall information required in the solution of two types of maintenance problems.

## Electronics

**On the Nonlinear Behavior of Electron-Beam Devices.** F. Paschke. *RCA Rev.*, June, 1957, pp. 221–242. 15 refs. Derivation of the nonlinear space-charge-wave equation and solution, for the case of a velocity-modulated electron beam (klystron), and of the three simultaneous linear differential equations into which this equation is split by third-order successive approximation. Equations for the gain and efficiency of a two-cavity klystron are given.

**Microwave Amplification by Maser Techniques.** W. V. Smith. *IBM J. Res. & Devel.*, July, 1957, pp. 232–238. 11 refs. Discussion of microwave amplification by stimulated emission of radiation (MASER), whose potentialities for broadband, short-transit-time amplification are presented.

**Shock-Spectrum as a Criterion of Severity of Shock Impulses.** Charles T. Morrow. *ASA J.*, May, 1957, pp. 596–602. 14 refs. Theoretical investigation to determine the significance, beyond the conclusions that can be drawn from Biot's work, of the first-order shock spectrum in relation to hardware of several degrees of freedom. Consideration is given to the special case of an undamped system with lumped constants, consisting of a cascaded set of mechanical resonators of successively decreasing impedance, such that the reactions of the resonators on the corresponding exciting masses can be neglected.

**Design Considerations in the First Stage of Transistor Receivers.** Larry A. Freedman. *RCA Rev.*, June, 1957, pp. 145–162. Analysis of noise performance of transistor r-f stages utilizing capacitive antennas and of transistor mixer stages utilizing loop antennas. The procedure for designing a transformer for optimum insertion-loss/image-rejection performances is outlined.

**R-F Power Ratings for Subminiature Coaxial Cables.** G. J. Mares and N. J. Sladek. *Elec. Mfg.*, July, 1957, pp. 140–143. Comparative data in polyethylene and two types of fluorocarbon dielectric cables along with specially designed connector systems.

**The Effect of the Recorder Time Constant on the Apparent Speed of Fading of a Radio Signal.** S. A. Bowhill. *J. Atmos. & Terrestrial Phys.*, No. 5/6, 1957, pp. 338, 339. AR DC-sponsored research.

**A High Amplitude Pulse Gate.** George A. Sample. *Electronic Ind. & Tele-Tech*, July, 1957, pp. 57, 94, 96–100 ff. Description of a pulse gate capable of passing or blocking positive pulses of 100 v. maximum amplitude and 0.25 microsec. minimum width.


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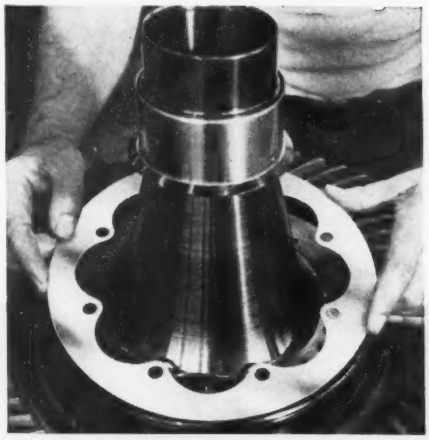

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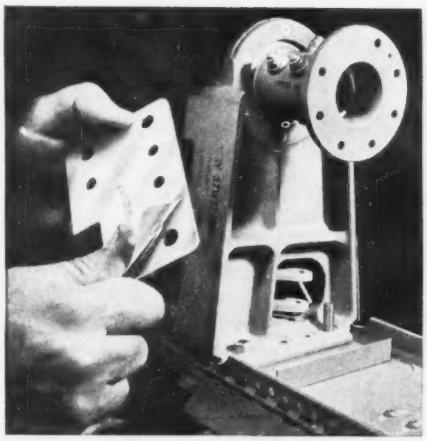

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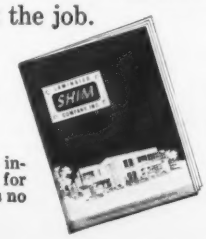


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**Hot Junctions and Collector Cut-Off Current.** Bernard Reich. *Electronic Ind. & Tele-Tech*, July, 1957, pp. 55, 56. Presentation of measured and calculated values of the cut-off current for a junction operated above ambient temperature. The data show that the only temperature-sensitive parameter is the saturation component.

**Survey of Low Level Modulators.** John H. Searcy. *USAF WADC TR 56-178*, Feb., 1956. 80 pp. 88 refs. Review of all known types of modulators, making absolute comparison principally on inherent noise and stability. In addition, amplitude linearity, frequency response, complexity, and other special limitations are considered.

**Multi-Valve Cathode Follower Circuits. I—Methods of Approaching the Ideal Buffer Stage Performance.** J. G. Thomason. *Wireless World*, July, 1957, pp. 310–313.

**Improvement of Binary Transmission by Null-Zone Reception.** F. J. Bloom, S. S. L. Chang, B. Harris, A. Hauptschein, and K. C. Morgan. *Proc. IRE*, July, 1957, pp. 963–975. ARDC-sponsored consideration of binary-data transmitting schemes in which the receiver prints out one of three symbols (single-null zone reception), or one of four symbols (double-null zone reception).

**Monitoring Task in Speech Communication.** James P. Egan. (*USAF CRC TN 56-65*)[*AD 98827*], *ASA J.*, Apr., 1957, pp. 482–489. USAF-supported quantitative description of the monitor's behavior, in situations involving several noisy channels, in terms of the operating characteristic and the articulation-criterion function. Two experiments are described.

**Special Issue: Report on Micro-Miniaturization.** *Electronic Des.*, July 1, 1957, pp. 16–39, 44–47, 50, 51. *Partial contents*: Component Development for Micro-Miniaturization, H. Stone. Micro-Miniaturization Requires New Thinking, C. Brunette and O. Stuetzer. Micro-Miniaturization—A Paradox? Micro-Miniature Techniques, W. W. Hamilton. Things are Getting Smaller. Micro-Miniaturization in Missiles, J. Moore. Miniaturization in Precision Switching. Micro-Miniature Inductors. Transmission Lines. Connectors. Thin Leaf Design Improves Micro-Miniature Relay Contacts. Tiny Transistor-Amplifier. Production Techniques.

**Applying Flexible Printed Circuits in Electronic-Equipment Design.** George Voida. *Mach. Des.*, July 11, 1957, pp. 124–131. Discussion giving specific consideration to types of materials and their commercial availability, conductor-laminate bond-strength properties, shaping characteristics, and processing and operating stability.

**Guide to Design of Electronic Equipment for Maintainability.** John D. Folley, Jr., and James W. Altman. *USAF WADC TR 56-218*, Apr., 1956. 174 pp. 11 refs. Discussion of factors in planning of maintainability, a schedule of steps to be taken in designing a maintainable system, and specific characteristics for equipment and maintenance procedures.

**Functional Packaging for New Era Airborne Electronics.** James Holahan. *Av. Age*, July, 1957, pp. 106–115 ff. Description of a joint WADC C&N Lab./RCA Airborne Systems Dept. program to find the optimum approach to the design of electronic gear for the limited space of high-performance aircraft. The program is broken down into three overlapping phases: Uniform Design Criteria, Reliability Criteria, and ARC-62 Development.

**Disk-Loaded Torsional Wave Delay Line. I—Construction and Test. II—Theoretical Interpretation of Results and Design Information.** P. Andreatch, Jr., and R. N. Thurston. *ASA J.*, Jan., 1957, pp. 16–25.

**Phase Retardation Design Curves for Solid Lossless Dielectric Panels.** Eino J. Luoma. *USAF WADC TR 56-116* [*AD 110514*], Feb., 1956. 23 pp. Series of graphs intended for use as a design tool by radome designers.

**Impedance Transformations by Extension of the Isometric Circle Method to the Three-Dimensional Hyperbolic Space.** E. Folke Bolinder. *J. Math. & Phys.*, Apr., 1957, pp. 49–61. 21 refs. USAF-Army-Navy-sponsored consideration of two problems in network theory: analysis or synthesis of a lossy, two-terminal-pair network from three measurements; and cascading of lossy, two-terminal pair networks.

**Application of the Smith Chart to General Impedance Transformations.** Harvel N. Dawirs. *Proc. IRE*, July 1957, pp. 954–956. ARDC-sponsored analysis showing how impedances may be calculated using the Smith Chart and associated techniques in much the same manner as for lossless transmission lines—even when the network is unsymmetrical and has complex image impedances and propagation constant.

**Automation of Environmental Testing.** Virlyn W. Walter. *ISA J.*, July, 1957, pp. 286–289. Description of fully automated testing and data-handling systems used in mass environmental testing of electronic components.

**Intermodulation Products for $v$-Law Biased Wave Rectifier for Multiple Frequency Input.** E. Feuerstein. *Quart. Appl. Math.*, July, 1957, pp. 183–192. 13 refs. Study in which the contour integrals expressed by Rice and Bennett for a rectifier are rewritten as improper integrals on the real line, plus constant terms. These integrals converge fast enough, in many cases, to be useful in numerical integration.

**Mixed-Path Ground-Wave Propagation. II—Larger Distances.** James R. Wait and James Householder. *J. Res.*, July, 1957, pp. 19–26. 10 refs. Generalization to a spherical earth of Wait's theoretical results relating to a flat earth. Extensive numerical results are given in graphical form for a mixed land-sea path at frequencies of 10, 20, 50, 100, and 200 kc./sec.

### *Amplifiers*

**Compensating Silicon Transistor Amplifiers.** S. H. Gordon. *Electronics*, July 1, 1957, pp. 184, 185. Presentation of the effects of impedance mismatch, feedback, and thermistor compensation for the grounded-emitter configuration at temperatures of 20° to 100°C.

**Transistors in High-Frequency Amplifiers.** W. Guggenbühl and M. J. O. Strutt. *Electronic & Radio Engr.*, July, 1957, pp. 258–267. 29 refs. Properties of transistors and their behavior in amplifier stages of the high-frequency region. The physical reasons for the frequency dependence of transistor parameters are considered, the formulas for the maximum gain in the common-emitter stages are presented, and the stability of high-frequency amplifier stages is discussed.

### *Antennas*

**D. F. Aerial System for Decimetre Wavelengths.** C. Clarke. *Electronic & Radio Engr.*, July, 1957, pp. 238–245. Discussion of two aerial systems suitable for direction finding on vertically and horizontally polarized transmissions. They are designed for a twin-channel cathode-ray type of instrument in which the azimuthal coverage is limited to a selected 90° sector.

### *Cooling*

**Fluid-Cooling an Airborne Transmitter.** James B. Humfeld. *Electronics*, July 1, 1957, pp. 170–172. Description of an amplifier employing six parallel output tubes in a self-rectifying six-phase circuit that eliminates the need for a separate power supply. Cooling is accomplished by immersion in silicone fluid.

**Novel Systems Will Cool Electronics at Mach 3 Plus. II.** C. F. Johnson. *Av. Age*, July, 1957, pp. 124–127. 13 refs. Description of vortex-tube and thermoelectric cooling systems.

### *Electronic Tubes*

**The Symbolic Coding of Information on Cathode Ray Tubes and Similar Displays.** Paul F. Muller, Jr., Raymond C. Sidorsky, Alec J. Slivinske, Earl A. Alluisi, and Paul M. Fitts. *USAF WADC TR 55-375*, Oct., 1955 (June, 1956). 123 pp. 22 refs. Summary of results of a series of eleven studies of the feasibility of several different types of symbols for the coding of information on cathode-ray tubes and similar displays for use in future air traffic control and related systems.

**A Low-Noise Klystron with High Power Output.** R. A. La Plante and G. A. Espersen. *Philips Tech. Rev.*, June 4, 1957, pp. 361–368. Investigation of the noise in klystron tubes and construction of a nontunable tube as a result of these experiments.

**A Traveling-Wave Frequency Multiplier.** D. J. Bates and E. L. Ginzton. *Proc. IRE*, July, 1957, pp. 938–944. USAF-Army-Navy-supported description of, and experimental results for, a tube which employs two helices in cascade—the output helix being a dispersive forward-wave one which operates at $S$ band and permits the selection of a particular harmonic by voltage tuning. A wide range of input frequencies can be used.

**Long-Persistence Three-Color Indicator Cathode-Ray Electron Tube.** Chester D. Beintema, Lorin L. Vant-Hull, and Sidney T. Smith. *USAF WADC TR 56-48* [*AD 110626*], May, 1956 (1957). 25 pp. Development of a tube capable of operation with magnetic rotating PPI yokes and suitable for application testing.

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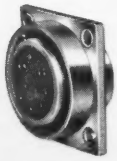

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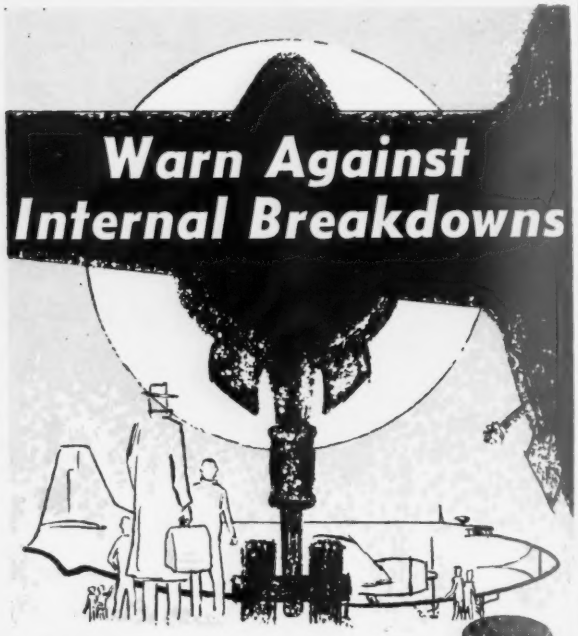


**LISLE** *Magnetic* **CHIP DETECTORS**

Safeguard aircraft engines and accessory units and provide a quick, positive means of determining the presence of ferrous metal chips or particles in lubricating oils by installing Lisle Magnetic Chip Detectors.

Attracted to the Detector by its powerful Alnico magnet, the particles bridge an electrically insulated gap between the magnet and Detector body. A ground check with a continuity tester — without removing the Chip Detector — indicates the accumulation of metallic particles.

**LISLE** *Magnetic* **PLUGS**

offer unusual protection anywhere there are moving parts in a fluid. The powerful Alnico or Cobalt magnet in a Lisle plug captures harmful metal particles present in the lubricant, keeping them from recirculating. Removal of these ferrous chips and shavings greatly reduces wear and damage to bearings, gears and other moving parts.

**Engineers:** Write for sample Magnetic Plugs for testing. State thread size. Complete catalog on plugs and chip detectors will be sent without obligation.

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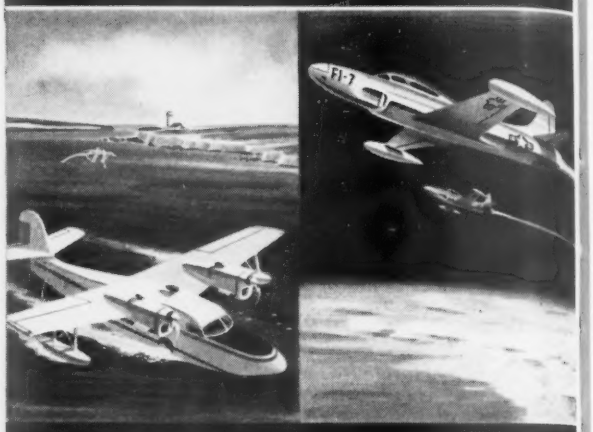
**From Water Level To Stratosphere...**



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**Electron Tube Operation as Influenced by Temperature and Voltage.** Appendix I—**Effect of Heater Voltage Modification on Reliability of An/ARC-27.** Appendix II—**A Study of Environmental Temperature and Pressure Effects on the Plate Dissipation Rating of Receiving Tubes.** Thomas H. Briggs. *USAF WADC TR 56-53 [AD 110455]*, Jan., 1956. 80 pp. 66 refs.

*Magnetic Devices*

**Change in Permanent Magnet Pole Strength; Factors of Influence and Measurement of Their Effect.** E. M. Briscoe. *Elec. Energy*, July, 1957, pp. 340–343.

**The Evolution of the Permanent Magnet; A Brief Review.** H. J. Meerkamp van Embden. *Philips Tech. Rev.*, June 4, 1957, pp. 358–360. 10 refs.

**Hall Effect and Ferromagnetism of Very Thin Nickel Films.** R. Coren and H. J. Juretschke. *J. Appl. Phys.*, July, 1957, pp. 806–809. 14 refs. ONR-supported method employing Hall effect measurements to determine the two constants and the magnetic properties at room temperature of nickel films which are less than 100 Å thick.

**Ceramic Ultrasonic Magnetostrictive Transducer.** H. D. Root and J. McDonald. (*Am. Ceram. Soc., 57th Annual Meeting, Cincinatti, Apr. 27, 1955.*) *J. Am. Ceram. Soc.*, Jan., 1957, pp. 1–5. Investigation of the magnetic and magnetostrictive properties of cobalt and nickel ferrite, and presentation of an evaluation method for a biased transducer.

**A Study of Permanent Magnets of the Barium Ferrite Type.** K. J. Sixtus. Appendix—**Some Remarks Concerning the Design of Barium Ferrite Magnets.** R. K. Tenzer. *USAF WADC TR 56-198 [AD 110551]*, Aug., 1956. 46 pp. Experimental investigation to improve the magnetic properties of the material and to add to the knowledge of the magnetization process.

*Noise & Interference*

**Mechanical Filter Design and Development.** Arthur L. Bernstein. *Sperry Eng. Rev.*, May-June, 1957, pp. 8–13. Discussion of the mechanical filter as a highly reliable device for stabilization and noise rejection, to meet the needs of accurate servosystems. Includes outline of filter design parameters, formulation of design procedures, and review of mechanical development problems such as flotation, material selection, and assembly and calibration methods.

**Optimum vs. Correlation Methods in Tracking Random Signals in Background Noise.** R. C. Davis. *Quart. Appl. Math.*, July, 1957, pp. 123–138. 10 refs. Application of the Cramér-Rao inequality to obtain an expression for the minimum error variance attainable.

**Downward Spread of Masking.** Walter Spieth. (*USAF CRC TN 56-11*) *[AD 110056] ASA J.*, Apr., 1957, pp. 502–505. USAF-supported experimental investigation to obtain pulsed pure-tone audiograms in quiet and in the presence of narrow bands of noise centered at 500, 1,000, 2,000, and 4,000 cps, and at several levels.

**Masking of Speech by Line-Spectrum Interference.** J. C. R. Licklider and New-

FIGHT VIBRATION WITH VIBRATION

# Now...shake-test to 5000 cps with 1750 lbs force!

HERE is an electrodynamic vibration exciter with highest operating frequency in its force range. The Model C10 VB exciter extends the range of vibration testing systems to 5000 cps with no table diaphragming or disturbing resonances under 5000 cps. Liquid cooled, it delivers up to 1750 lbs force output for continuous sinusoidal testing ... and extends the range of random motion testing to 5000 cps.

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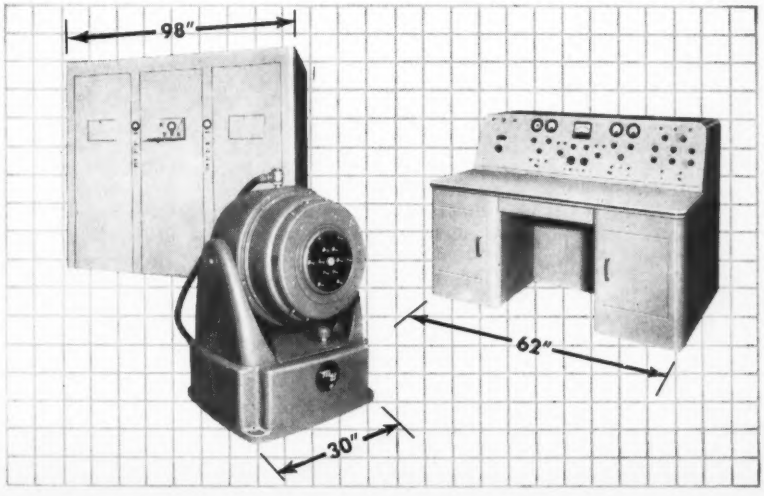


man Guttman. (*USAF CRC TN 56-66*) [*AD 98831*] *ASA J.*, Feb., 1957, pp. 287–293; Discussion, pp. 293–296. 13 refs. USAF-supported investigation involving two series of intelligibility tests and comparison of these tests with experiments using continuous-spectrum random noise.

### *Oscillators & Signal Generators*

**Design of Oscillators. I.** Keats A. Pullen, Jr. *Electronic Des.*, July 1, 1957, pp. 52–55. Method using conductance curves in which the active device (tube, transistor, or similar device) is coordinated with the balance of the circuit. Techniques are presented for the design of oscillators from a small signal point of view with emphasis on sinusoidal oscillators.

**A Very Low Frequency Three-Phase Oscillator.** M. D. Armitage. *Electronic Eng.*, July, 1957, pp. 318–323. Discussion of a cathode-feedback circuit to increase the time constant of the resistance-capacitance network in a phase-tilt oscillator for the frequency range 0.01 to 40 cps, using only five valves.

### *Radar*

**Graphs Simplify Ferrite Choice in Radar Design.** Willard Hughes. *Av. Age*, July, 1957, pp. 118–123.

**Microwave Remotes Aid Air Traffic Control.** E. K. Peterson, H. R. Ulander, R. N. Hargis, and E. Hajic. *Electronics*, July 1, 1957, pp. 144–147. Description of a relay system that transmits long-range surveillance-radar information along with GCA and height-finding information over 250 miles. Signals for control of vital radar functions and composite video information are transmitted using multiplexing techniques in conjunction with encoding and decoding.

**Optimizing the Dynamic Parameters of a Track-While-Scan System.** Jack Sklansky. *RCA Rev.*, June, 1957, pp. 163–185. Analysis of a system characterized by two dynamic parameters—one correcting the position error and the other correcting the velocity error. Charts and formulas are derived to describe the stability, transient response, noise, and maneuver error as functions of the dynamic parameters, and to serve as tools for a proposed optimization scheme, illustrated by a numerical example. A formula for the mean-square response of the system to white noise is also derived.

**Problems in Protection of Radar Receivers.** G. D. Speake. *Electronic Eng.*, July, 1957, pp. 313–317. 14 refs. Survey of the requirements for a switch capable of providing a large measure of isolation between the receiver and the transmitter of a pulsed radar system during the period of pulses. Other methods of isolation, such as the unidirectional waveguide components, are also noted, along with modern developments in thermionic valves which may reduce the degree of protection required by the receiver.

### *Semiconductors*

**The Effect of Nuclear Radiation on Selected Semiconductor Devices.** G. L. Keister and H. V. Stewart. *Proc. IRE*, July, 1957, pp. 931–937. 14 refs. ARDC-supported experiments involving exposure of samples of both germanium and silicon devices to an environment consisting of either a fission-produced gamma spectrum or a combined neutron and gamma spectrum, as obtained in the graphite region of the Materials Testing Reactor in Scoville, Idaho.

**Behavior of Noise Figure in Junction Transistors.** Edward G. Nielsen. *Proc. IRE*, July, 1957, pp. 957–963. Presentation of a method for calculating the noise figure in terms of generator resistance, d.c.-emitter current, base resistance, low-frequency alpha, and alpha cutoff frequency. Also given are the frequency variation of the noise figure, and the conditions for minimizing the noise figure.

**Very Narrow Base Diode.** R. H. Rediker and D. E. Sawyer. *Proc. IRE*, July, 1957, pp. 944–953. USAF-Army-Navy-supported description of a technique for fabricating semiconductor diodes with rectifying junction to ohmic contact distances of the order of microns. Small-signal applications at U.H.F. are discussed and a computer diode is described that switches at speeds up to 5 mc. and has the advantageous combination of low forward-voltage drop and high-frequency capability.

**Transistor Application in Aeronautical Equipment.** Franklin W. Campbell. *Sperry Eng. Rev.*, May–June, 1957, pp. 14–18. Outline of the use of semiconductors and miniaturized circuitry in recently developed aeronautical equipment. Problems involved in conversion from vacuum tube units to transistorized versions are presented, and several actual miniaturized components are described.

**Gamma Irradiation of Germanium and Silicon Transistors.** Ralph J. Panos. *USAF WADC TN 56-115*, Mar., 1956. 103 pp. Investigation comparing the electrical measurements made on transistors before and after radiation. Parameters measured are the current gain (alpha) noise figure, input impedance ($h_{11}$), and the saturation current of the collector diode ($I_{co}$).

**Influence of Surface Oxidation on Alpha$_{cb}$ of Germanium P-N-P Transistors.** J. Torkel Wallmark. *RCA Rev.*, June, 1957, pp. 255–271. Theoretical and experimental investigation with results indicating that oxidation of the germanium surface is a major factor influencing surface recombination and, thereby, the current-transfer ratio of germanium P-N-P transistors.

**Design for an Improved High-Frequency Transistor.** C. Thornton, J. Roschen, and T. Miles. *Electronic Ind. & Tele-Tech*, July, 1957, pp. 47–49, 124. Description of a silicon surface alloy transistor, designed to meet military high-temperature and high-frequency application requirements, that utilizes a thinner base width and smaller diameter electrodes.

**The Question of Surface Recombination.** V. L. Bonch-Bruevich. *Soviet Physics - Tech. Physics*, No. 6, 1957, pp. 1,111–1,114. Translation. Analysis leading to the conclusion that, generally speaking, the experimentally determined quantity, usually termed the rate of surface recombination, is a complex expression which takes into account the joint action of the two different factors.

## Equipment

**Kinetic Heating Simulation in Aircraft Structures.** *Elec. Energy*, July, 1957, p. 343. Description of the development by Metropolitan-Vickers Electrical Co., Ltd., of a complete system for the laboratory simulation of the conditions likely to be met during high-speed flight, and for the study of deformations caused by thermal stress where unequal temperature distributions result from changes in speed.

**Advantages of Test to Failure.** Harry R. Powell. *Sperry Eng. Rev.*, May-June, 1957, pp. 19–22. Discussion of experience in testing to failure, current uses of the method, and cost considerations.

**Testing for Reliability.** Robert Lusser. *Ordnance*, July-Aug., 1957, pp. 191, 192. Discussion comparing the relative merits of testing complex equipment to limits and testing it to failure. The latter procedure is advocated.

**Aviator's Oxygen.** *Lockheed Field Serv. Dig.*, July-Aug., 1957, pp. 3–11. Discussion of oxygen-handling procedures and the servicing of the oxygen systems on Constellation and 1649A aircraft.

### *Electric*

**Thermal Considerations of Generators in High-Speed Aircraft.** Alexander Kusko. *Elec. Eng.*, July, 1957, pp. 594–598. Two-part study to determine the maximum temperature at which the electromagnetic rotating-machine method of energy conversion is feasible, and to determine optimum combinations of generators and cooling systems that employ presently available materials and components.

**New Horizons for Battery Power.** Arnold E. Look, Jr. *Electronic Ind. & Tele-Tech*, July, 1957, pp. 34–36. Description of new types of batteries and the extensions made in their shelf life and service life.

**Flexible-Standard AC Motors.** John Barrett. *Aero. Purchasing*, July, 1957, pp. 26, 27, 42. Discussion covering the development and production by Jack and Heintz, Inc., of an integrated family of standard motors, and description of the advantages of the new standards in terms of motor-part interchangeability and expedited delivery.

**Oświetlenie Samolotu.** Kwiryn Zuchowicz. *Tech. Lotnicza*, Mar.-Apr., 1957, pp. 37–48. 11 refs. In Polish. Description of various aircraft lighting system.

**Ground Power Equipment for Support of Air Force Weapons.** T. B. Holliday. *Elec. Eng.*, July, 1957, pp. 600–605. Survey which shows that weapons of the future can be served by five types of power units: (1) ramp unit, (2) trailer-mounted mobile unit, (3) stationary or portable unit, (4) fixed-base power unit, (5) electric motors.

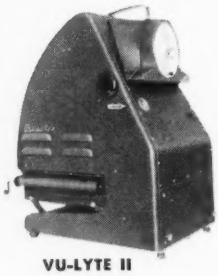
### *Hydraulic & Pneumatic*

**MS Flareless Hydraulic Fittings.** Warner McCarthy. *Aero. Purchasing*, July, 1957, pp. 28–30. Description of the fittings which are intended primarily for high-pressure gas or fluid systems and for service which may be subjected to severe vibrations. Their operation and advantages are cited.

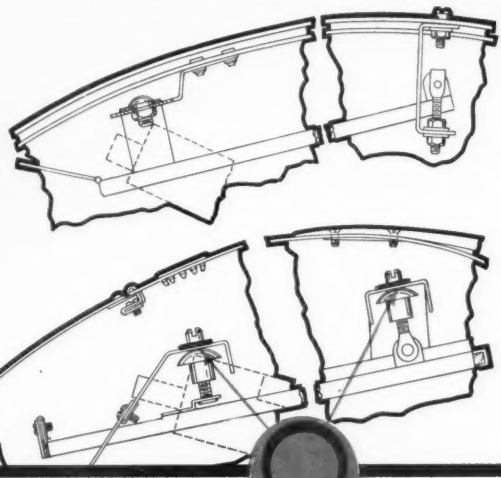
# Waldes Truarc Rings cut assembly costs, improve performance of precision photo-optics equipment

**Charles Beseler Co., E. Orange, N. J. uses Waldes Truarc Retaining Rings in 3 applications shown.**

**REFLECTING MIRROR ASSEMBLY IN OPAQUE PROJECTOR**



VU-LYTE II PROJECTOR



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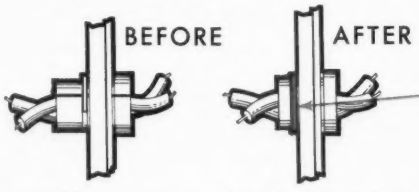
"The front surface mirror is the most precise optical element in a properly-functioning opaque projector," Beseler writes. "Previously we used this extremely cumbersome means of holding the mirror in position. As mirror adjustments are always required and the mirror is extremely delicate, our spoilage was terrific."

**AFTER**

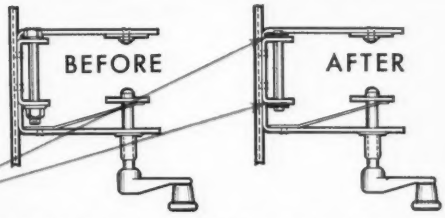
"Two Truarc Series 5100 Rings made possible complete redesign of the mirror assembly. Now mirrors can be adjusted from *outside* the projector. Rejects now are practically nil. More precise adjustment of the mirror is possible. And because of the greater ease in adjustment, we have cut labor costs $2.00 per unit."

**HEAT ASSEMBLY IN PRINT DRIER**




Here a Waldes Truarc crescent ring, Series 5103, replaced a split collar and clamping ring. Results: labor costs cut 50¢ per unit because of greater ease of assembly. Drier provides more uniform heating.

**35 MM MICRO-FILM NEGATIVE CARRIER IN ENLARGER**




2 Waldes Truarc Series 5133 E-Rings replaced 2 cap nuts—at a saving of 20¢ per unit in labor costs.

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**Hydraulic Control Valves. V—Valve Circuits.** John J. Pippenger. *Prod. Eng.*, July, 1957, pp. 197–202. Discussion of factors governing the choice of valve, its function in the circuit, and the problems that may be anticipated and avoided.

**Hydraulic Drive and Controls Help Test Aircraft Fuel Tanks.** Davis Hutchinson. *Appl. Hydraulics*, July, 1957, pp. 111–114. Description of a mechanism to perform vibration and slosh tests on fuel tanks.

**Series Synchronizing Circuit to Extend a Rocket Launching Beam.** E. Ashley. *Appl. Hydraulics*, July, 1957, pp. 106–109, 114. Discussion of the advantages and limitations of a series circuit and application to a rocket-launching system.

**Improving Fatigue Life of Formed Stainless Steel Hydraulic Tubing by Prestressing.** C. S. Yen and B. V. Whiteson. *USAF WADC TR 56-120*, May, 1956 (1957). 51 pp. Tests on formed corrosion-resistant steel tubing, conforming to specification MIL-T-6845, to determine the effect of prestressing on its fatigue life.

**Spring-Loaded Cylinder Coordinates Hydraulic, Mechanical Systems.** *Des. News*, July 1, 1957, pp. 20, 21. Application of a spring-loaded cylinder called a "bungee" for coordinating the hydraulic servo and mechanical follow-up systems of the fore and aft speed brakes in a FJ-4B fighter.

**Flareless Hydraulic Fittings Keep F-104 "Dry".** Frank W. Cowdrey. *Av. Age*, July, 1957, pp. 64–68 ff.

## Flight Operating Problems

**The Effect Upon the Output of a Complex Man-Machine System of Quickening and Damping a Derivative Feedback Display.** Malcolm L. Ritchie and Harold E. Bamford, Jr. *USAF WADC TR 57-103* [*AD 118069*], Apr., 1957. 25 pp. Investigation resulting from the mounting of a gyroscopic turn indicator on the sloping panel of an all-weather interceptor which leads to a negative quickening of the display indication. Experiments in an electronic flight simulator demonstrate the adverse effect of negative quickening and the favorable effect of positive quickening on the output of the man-machine system.

**Cruise Control System Proposed for Jet Aircraft.** H. F. Kidder. (*SAE Natl. Aero. Meeting, New York, Apr. 2–5, 1957, Preprint 96.*) *SAE J.*, July, 1957, pp. 83–85. Abridged. Discussion of proposed integrated system to display cruise data. An airborne computer is to deliver the data that is needed.

## Flight Testing

**Certificate of Airworthiness Flight Testing; A Review of Some of the Problem Areas in the Certification Testing of Large Civil Transport Aircraft.** D. P. Davies. *RAeS J.*, July, 1957, pp. 467–474.

**Flight Testing Stability Augmentation Devices for High-Performance Fighters.** A. W. Blackburn. (*IAS 25th Annual Meeting, New York, Jan. 28–31, 1957.*) *Aero. Eng. Rev.*, Sept., 1957, pp. 75–82. Discussion which emphasizes that artificial stability is changing from a desirable appendage to an absolute necessity as performance capabilities increase. Open-loop stability devices are described which include yaw dampers, pitch dampers, roll dampers, and static longitudinal stability augmenters usually referred to as "Mach boxes." Standard tracking maneuvers are also designed for determination of ultimate value.

## Fuels & Lubricants

**Evaluation Tests of Arylurea-Silicone Greases in Aircraft Equipment.** Appendix I—**Physical and Chemical Test of Arylurea-Silicone Greases.** Appendix II—**Members of Industry who Cooperated with the Materials Laboratory in the Evaluation Program.** Herbert Schwenker. *USAF WADC TR 56-475* [*AD 110634*], Dec., 1956. 20 pp.

**The Preparation and Properties of Some Fluorine-Containing Diesters.** Appendix I—**Physical Properties and Analytical Data.** Appendix II—**Experimental Procedures.** Joseph F. O'Brien, Robert Filler, Jack V. Fenner, and George Rappaport. *USAF WADC TR 56-11* [*AD 110674*], Dec., 1956. 31 pp. 28 refs. Description of the preparation and properties of six different types of fluorine-containing diesters for possible use as high-temperature lubricants and hydraulic fluids. The infrared spectra of the diesters are recorded and the effect of fluorine atoms on the ester carbonyl frequency is described.

**Starting and Running Low Temperature Torques.** Bernard Rubin. *USAF WADC TR 56-175*, May, 1956. 16 pp. Presentation of the data for greases in size 104, 204, and 306 bearings. A procedure is used which is under investigation by the ASTM Technical Committee G on Lubricating Grease, and recommendations are made for the improvement of test procedures for specification purposes.

**Development of a Micro Method for the Determination of Aliphatic Aldehydes.** Earl W. Malmberg and Boris Weinstein. *USAF WADC TR 56-516*, Nov., 1956 (1957). 27 pp. 12 refs.

**Ethylene Oxide as a Monopropellant.** Stanley A. Greene and Leonard J. Gordon. *Jet Propulsion*, July, 1957, pp. 798, 799. Study of the chamber gases of an ethylene oxide monopropellant motor and comparison of the experimental gas composition with the theoretically calculated ones.

**Decomposition of Hydrogen Peroxide Vapor on Relatively Inert Surfaces.** Charles N. Satterfield and Theodore W. Stein. *Ind. & Eng. Chem.*, July, 1957, pp. 1,173–1,180. 36 refs. Experimental investigation to compare the relative activities of glass, polymer, and metal surfaces, and to obtain useful data on hydrogen peroxide vapor decomposition.

**Utilization of High Energy Fuel Elements.** Earl A. Weilmuenster. *CCDA Spring Meeting, French Lick, Ind., May 13, 14, 1957.* 30 pp. Review of requirements for high energy fuels, which concludes that only derivatives of light weight elements should be considered. The research and development program of Olin Mathieson Corporation on boron-containing fuels is discussed.


**Long Range Planning and Research at Marquardt...**

*by*
*Roy E. Marquardt*
*President*

Although ramjet development in the Powerplants Division is the major activity here at Marquardt, there are three other divisions carrying on significant work; Controls and Accessories, Test, and Long Range Planning and Research.

The youngest of these Divisions is Long Range Planning and Research. Headed by John Drake, and numbering 50 engineers, the Division has two primary functions:

PLANNING — anticipating product trends in areas where we now operate or might enter. Actually this planning is done in a staff capacity, and normally the results end up as recommendations.

SUPPORT — to the other divisions, by introducing product improvements which offer promise for the future. These improvements generally involve a small scale program to establish the idea as feasible. This research function also may be concerned with areas which do not fit into present Marquardt projects.

Long Range Planning and Research was begun in 1954. One of its first studies concerned areas where the ramjet can now be used or where it might be used in the foreseeable future. To date some exciting new powerplant cycles have been plotted. Some are variations of cycles now in existence, others are radically different.

Projects also have probed new "exotic" fuels, new types of diffusers, accessory systems, and controls. One phase of Aircraft Nuclear Propulsion is now being explored.

Ground was broken near Newhall, California recently for a research test center. This aerodynamic facility will have testing capabilities to Mach 14.5 as a wind tunnel and Mach 10 for free jet testing with excellent simulation of full scale flight conditions (Reynolds Number). In addition, it will permit simulation of combustion conditions to Mach 8 and altitudes above 150,000 feet.

Within this Division, research engineers will find a spectrum of research engineering opportunities, including:

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| DESIGN | AERO-THERMODYNAMICS |
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For information about these positions and the professional engineering environment at Marquardt, we invite you to write Jim Dale, Professional Personnel, today.

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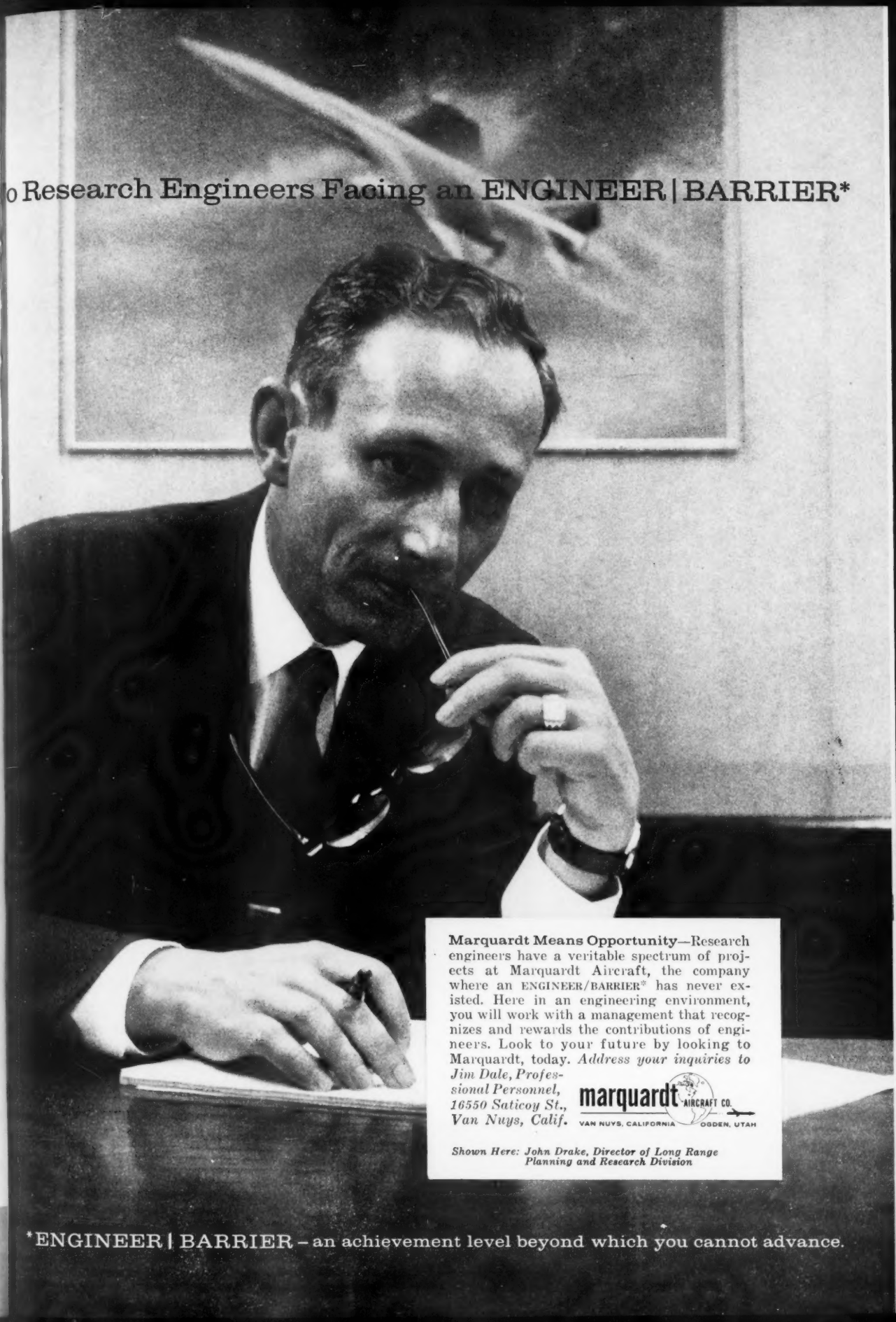
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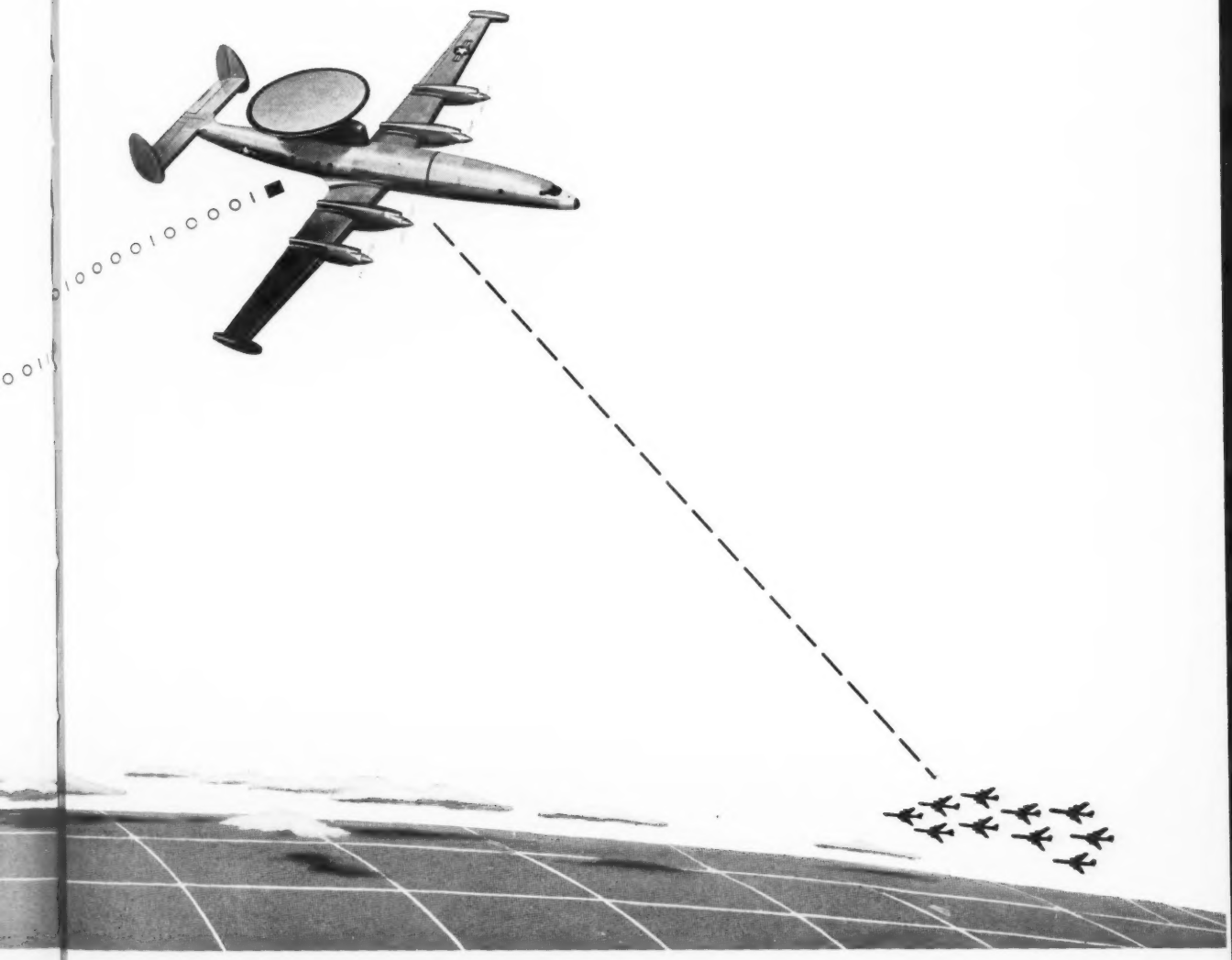

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**Development of an Apparatus for Warming Hydrogen Peroxide by Its Own Controlled Decomposition.** Johann G. Tschinkel and Arlin E. Graves. *Jet Propulsion*, July, 1957, pp. 796–798.

**Applied Research and Product Development for Rocket Propellants.** Allen R. Deschere. *CCDA Spring Meeting, French Lick, Ind., May 13, 14, 1957.* 16 pp. Discussion of the laboratory phase and the pilot plant phase of solid rocket-propellant development.

**Homogeneous Solid Propellants and the Chemical Industry.** Lyman G. Bonner. *CCDA Spring Meeting, French Lick, Ind., May 13, 14, 1957.* 6 pp. Review of the development in methods for solid propellants.

**Fluorine Derived Chemicals as Liquid Propellants.** John F. Gall. *CCDA Spring Meeting, French Lick, Ind., May 13, 14, 1957.* 10 pp. Discussion of marketing possibilities of rocket propellants, and the use of fluorine compounds as rocket fuel oxidizers. Properties of several such compounds are given, along with their handling characteristics.

## Instruments

**Condenser Microphones for Measurement of High Sound Pressures.** John K. Hilliard and Walter T. Fiala. (*ASA 50th Meeting, Providence, Dec. 16, 1955.*) *ASA J.*, Feb., 1957, pp. 254–260. Derivation of expressions leading to the evaluation of the nonlinear distortion of the described equipment, description of the construction of several of its elements, and presentation of performance data.

**Corrections for the Oscillating-Disk Viscometer.** J. Kestin and H. E. Wang. (*ASME Annual Meeting, New York, Nov. 25–30, 1956, Paper 56–A–34.*) *J. Appl. Mech.*, June, 1957, pp. 197–206. 13 refs.

**Shock Testing: Aid to Design.** C. A. Mills. *Aircraft*, June, 1957, pp. 39, 41, 89. Discussion of the purpose of shock testing and a description of various test rigs.

**Symbols and Terminology for Automatic Control Systems.** *Elec. Mfg.*, July, 1957, pp. 149–151, 290.

**Quantitative Design of Servo Systems by Frequency-Response Methods. I—Terms Affecting Gain and Phase.** J. M. Nightingale. *Mach. Des.*, July 11, 1957, pp. 132–136.

**How to Select Flowmeters.** Ralph Shapcott. *ISA J.*, July 1957, pp. 272–274. Presentation of a selection chart for the four basic flowmeter types, along with a method for estimating costs.

**Gyroscopes and Their Properties; Operating Principles of Typical Variations.** Joseph A. Volk. *Missile Des. & Devel.*, July, 1957, pp. 10, 11.

**Control Knob Arrangement Can Save Aircraft Instrument Panel Space.** James V. Bradley. (*Aero. Med. Assoc., 27th Annual Meeting, Chicago, Apr. 18, 1956.*) *J. Av. Med.*, June, 1957, pp. 322–327. Experimental investigation to determine which of two knob arrangements is the more economical and provides the greater safety from inadvertent touching of the wrong knob.

## Lighter-Than-Air

**The Flight of the Snow Bird.** *Res. Rev.*, June, 1957, pp. 1–13. Description of record-breaking endurance flight by Navy blimp ZPG-2.

## Machine Elements

**Zasady Racjonalnego Projektowania Mechanizmów.** Leonid N. Reszetow. *Arch. Budowy Maszyn*, No. 1, 1957, pp. 1–22. In Polish, with summaries in English and Russian. Development of a method for ensuring reliable performance in a mechanism (wedge, cam, yoke, spur gears, planetary gearing, etc.) with large tolerances in the dimensions of its parts, by selection of a suitable design. For this purpose, the mechanism should be statically determinable—i.e., it should contain no passive joints.

**General Equations for Finding Cam Curves and Cutter Pitch Curves.** H. H. Pan. *Mach. Des.*, July 11, 1957, pp. 137–140.

**Permissible Backlash Between Gear Teeth.** W. A. Tuplin. *The Engr.*, June 21, 1957, pp. 951–953. Method for estimating the impact loading that is imposed on a pair of gears by taking up backlash under full-load torque.

## Maintenance

**Evaluation of Failure Data. I.** H. I. Zagor. *Arma Eng.*, May–June, 1957, pp. 10–13. 11 refs. Method involving the use of graphs of failure rate vs. operating time and the testing of data for adherence to Poisson and negative binomial distribution. It is shown that cumulative probability techniques can be used to select items requiring immediate reliablity attention. Procedures are applicable to evaluating equipment and its maintenance methods, directing and guiding reliability improvement and future designs, and estimating spares.

## Materials

**Influence of Crucible Materials on High-Temperature Properties of Vacuum-Melted Nickel-Chromium-Cobalt Alloy.** R. F. Decker, John P. Rowe, and J. W. Freeman. *U. S., NACA TN 4049*, June, 1957. 34 pp. Experimental investigation of the effect of induction-vacuum-melting practice on the high-temperature properties of 55Ni-20Cr-15Co-4Mo-3Ti-3Al alloy.

**Electronic Materials at Elevated Temperatures.** James W. Ballard. *USAF WADC TN 57–211*, May, 1957. 8 pp. Discussion of materials for use above 200° C. These include magnetic, ferroelectric, dielectric and insulating, conductor, and semiconductor materials.

**Ferroelectric Materials Survey with Particular Interest in Their Possible Use at High Temperatures.** Charles F. Pulvari. *USAF WADC TN 56–467 [AD 110489]*, Feb., 1957. 68 pp. 134 refs. Compilation of ferroelectric material data of the oxygen octahedra type, emphasizing data on high-temperature properties and including descriptions of crystallization conditions where known.

**Titanium Bests Steel in Landing Gear Fatigue Tests.** Frank H. Vandenburgh. *Av. Age*, July, 1957, pp. 84–87 ff.

### *Ceramics & Ceramals*

**Resistivity Characteristics of Some Ceramic Compositions Above 1000°F.** H. R. Wisely. (*Am. Ceram. Soc., 57th Annual Meeting, Cincinnati, Apr. 27, 1955.*) *Am. Ceram. Soc. Bul.*, Apr., 1957, pp. 133–136. Experimental investigation of a number of ceramic compositions in order to obtain a material suitable for use as a thermistor for measuring temperatures of the exhaust gases in jet-type engines.

**Cutting and Grinding Ceramics.** R. F. Rea and J. W. Ripple. *Am. Ceram. Soc. Bul.*, May, 1957, pp. 163–167.

**Effect of Ceramic Coatings on the Creep Rate of Metallic Single Crystal and Polycrystalline Specimens.** J. R. Cuthill and W. N. Harrison. *USAF WADC TR 56–85*, Apr., 1956. 45 pp. 13 refs.

### *Corrosion & Protective Coatings*

**Preparation of Protective Coatings by Electrophoretic Methods.** Allen C. Werner, James J. Shyne, Harold N. Barr, and Bernard Triffleman. *USAF WADC TR 56–521 [AD 118224]*, Apr., 1957. 46 pp.

**Evaluation of Thin Iron Films as Sensitive Corrosion Indicators.** David Roller. *USAF WADC TR 56–237*, June, 1956. 32 pp. 28 refs. Investigation of such variables as film thickness and film substrates, as they affect the corrosion rates in various humidities.

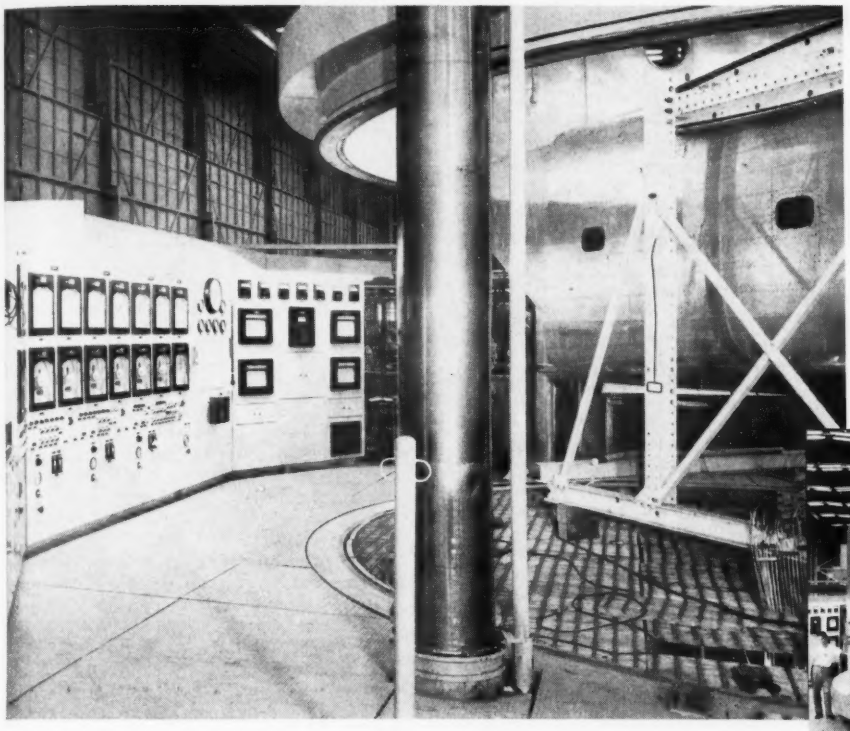
**Development of an Improved Corrosion Inhibitor for Water-Alcohol Solutions.** Dwight B. Conklin, Brock G. Peacock, and James E. Cole. *USAF WADC TR 55–345 [AD 97141]*, July, 1956 (1957). 75 pp. 62 refs. Description of a material which inhibits corrosion of steel, stainless steel, and aluminum alloys; is soluble in methanol, ethanol, water, or mixtures of the liquids; and lowers the surface tensions of the liquids.

**Corrosion and Ignition of Titanium Alloys in Fuming Nitric Acid.** John B. Rittenhouse, Nicholas D. Stolica, Stephen P. Vango, Julia S. Whittick, and David M. Mason. *USAF WADC TR 56–414 [AD 118028]*, Feb., 1957. 57 pp. 28 refs. Study of the susceptibility to ignition reactions, the tendency toward stress-corrosion cracking, and the corrosion rates of titanium and its alloys, all as a function of the chemical composition and temperature of fuming nitric acid.

### *Metals & Alloys*

**Retainer Materials for Aircraft Gas-Turbine Bearings.** Peter F. Mataich and F. Clifton Wagner. *USAF WADC TR 56–294 [AD 97235]*, Aug., 1956 (1957). 28 pp. Experimental investigation of additive materials including borides, carbides, and silicides.

**The Nature of Aftereffect in Metals.** D. M. Vasil'ev. *Soviet Physics - Tech. Physics*, No. 6, 1957, pp. 1,328–1,336. Translation. Discussion of the nature of the phenomenon leading to the residual variation of the dimensions of specimens which have been heated after being subjected to plastic deformation. A rheological circuit is proposed which consists of two



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# Servicing Rocket Engines

## Part II: Product Improvement

*by Fred Barker*

*In this, the second of two articles describing the activities of service engineers and service representatives at Reaction Motors, Inc., Mr. Barker, Supervisor of the Product Service Department, illustrates how the technical "know-how" described in Part I is utilized by the department in the area of Product Improvement.*

A good product can always be improved—particularly by those working closest to it. RMI's Product Service Department accepts this as a continuous challenge as it works with rocket engines and related components. The rewards of such a philosophy are three-fold: a superior, more easily serviced product, a pleased customer and the personal satisfaction of accomplishment.

At RMI we concentrate on four areas in the improvement of rocket engines: serviceability, reliability, safety and performance. For instance, in the area of reliability, initial ground runs on RMI's 6,000-lb. thrust engine in the Bell X-1A airplane frequently resulted in fuel pump cavitation upon starting the powerplant. Our service men traced the probable cause to the relocation, during installation, of the outlet port on the fuel diffuser case. It was found that air was being trapped in the case. This is a perfect example of how a seemingly minor change can radically affect engine reliability. To overcome this problem, the fuel pump was equipped with a bleed valve that automatically bled the entrapped air overboard during the liquid oxygen prime period prior to each engine start. Reliability was restored at the cost of adding another component, but installation demands could be satisfied only by this procedure.

Our service engineers and representatives often recommend design changes to improve products. A typical example of this is the way RMI worked with the National Advisory Committee for Aeronautics to improve the normal engine reliability of our 6,000-lb. thrust engine in the Douglas D-558-II airplane. The thrust chambers had failed to start on several random occasions. The trouble was traced to mechanical failures of the poppet retainer in the igniter oxygen poppet valve. This prevented the igniter from firing to start the thrust chamber. Service engineers in the home office then modified the poppet valve for greater mechanical strength. This improvement was proved successful by poppet valve tensile pull tests and igniter firing tests; replacement parts were obtained and installed in all engines in the field to prevent future failures from this cause.

Anxious to improve performance of the X-1E airplane, NACA considered the possibility of incorporating nozzle extensions on the thrust chambers of the X-1E's RMI rocket engine. After Service Department preliminary design work was accepted by NACA, installation problems were resolved with NACA by one of our service engineers. He then firmed nozzle extension design, assembly and installation details. This change proved so effective that now—for the same propellant consumption—thrust at altitude is appreciably greater. A good engine has been modified to perform even better.

Another function of the Service Department in its role to keep rocket engines going is the handling of engineering changes, all of which must be coordinated through and approved by the customer. Before any modification is made, RMI service engineers prepare "engineering change proposals" for approval by the customer. Upon this approval, the changes are incorporated into the affected drawings, and service bulletins are prepared to guide field personnel in effecting the change. Conversion kits are prepared, where needed, and service handbooks are revised.

Because the functions of RMI's Product Service Department are so varied, the men who make it up must be more than talented professionals. They must also have the traits of versatility and willingness to tackle new and different assignments. And—because our team is expanding—we would like to talk to *you* if you believe you have the professional qualifications and versatility that are so essential in good service men.

*If you desire reprints of this two-part article by Mr. Barker, or would like to receive additional information about RMI, write to our Information Services Coordinator, Reaction Motors, Inc., 22 Ford Road, Denville, New Jersey.*

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parallel-connected Maxwell elements, and the dependence of the relaxation times of the circuit elements upon the temperature and rate of heating is given.

**The Properties of Constructional Metals as a Function of Temperature and Strain Rate in Torsion.** Appendix I—**Calculations of the Torsion Values Reported.** Appendix II—**An Interpretation of Ductile Brittle Transitional Behavior in Terms of the Flow Curve.** E. P. Klier, N. Feola, A. Viggiano, and V. Weiss. *USAF WADC TR 56-216 [AD 110559]*, Nov., 1956 (1957). 186 pp. 27 refs. Experimental investigation on seven structural metals tested in torsion at four strain rates and at selected testing temperatures. The torque-twist relationships are determined at the three lowest strain rates. The work confirms the trends established by Work and Dolan.

**An Investigation of Intergranular Oxidation in Stainless Steels and High-Nickel Alloys.** Clarence A. Siebert, Maurice J. Sinnott, Lynn H. DeSmyter, and Harry M. Ferrari. *USAF WADC TR 55-470, Pt. 2, [AD 110440]*, Oct., 1956. 42 pp. Microscopic measurements on specimens from Chromel ASM, Hastelloy B, and commercial and vacuum-melted type 310 stainless steel alloys oxidized for 100-hr. periods in the stressed condition.

**Theory of Precipitation Hardening: Isotropically-Strained System.** R. O. Williams. *Acta Metallurgica*, July, 1957, pp. 385-392. 18 refs. Calculations to show that appreciable strengthening can result from the hydrostatic interaction between edge dislocations and isotropically strained matrix and precipitate.

**Plastic Aftereffect in Metals.** D. M. Vasil'ev and L. S. Evlashin. *Soviet Physics - Tech. Physics*, No. 6, 1957, pp. 1,322-1,327. Translation. Examination of the residual variations of specimens, variations which are observed when these specimens are heated after preliminary plastic deformation by inflection or by torsion (plastic aftereffect).

**A Survey of the Effect of Austenitizing Temperature and Rate of Continuous Cooling on the Structure and 700°F to 1200°F Properties of Three Low-Alloyed Steels.** Kenneth P. MacKay, A. Phillip Coldren, Adron I. Rush, and James W. Freeman. *USAF WADC TR 55-388*, Jan., 1956. 67 pp.

**Design Properties of High-Strength Steels in the Presence of Stress Concentrations and Hydrogen Embrittlement. III—The Response of High-Strength Steels in the Range of 180,000-300,000 psi to Hydrogen Embrittlement from Cadmium Electroplating.** E. P. Klier, B. B. Muvdi, and G. Sachs. *USAF WADC TR 56-395, Pt. 3 [AD 118167]*, Mar., 1957. 116 pp. 21 refs. Sustained-load, rotating-beam fatigue, and bending tests.

**A New Concept of Hydrogen Embrittlement in Steel.** J. G. Morlet, H. H. Johnson, and A. R. Troiano. *USAF WADC TR 57-190 [AD 118155]*, Mar., 1957. 42 pp. 16 refs. Evaluation of the influence of plastic strain on the aging characteristics of hydrogenated 4340 steel.

**Development of Cast Iron-Base Alloys of Austenitic Type for High Heat-Resistance and Scale-Resistance.** F. Eberle, J. H. Hoke, and W. E. Leyda. *USAF*

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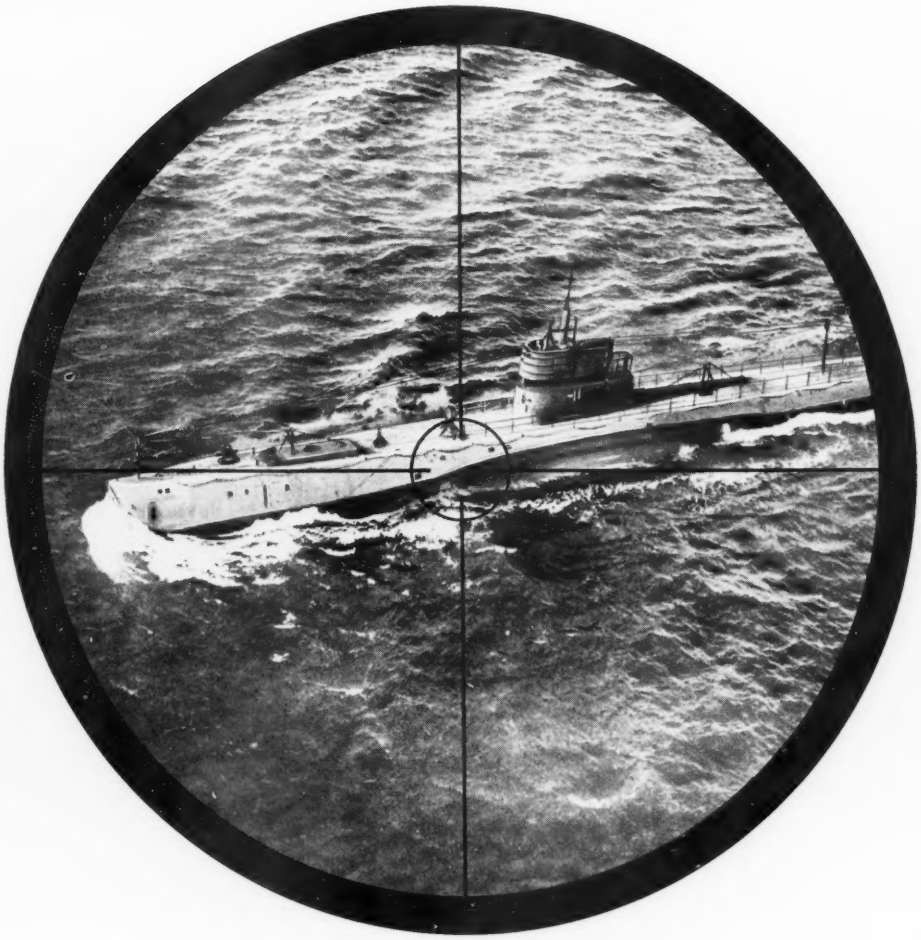

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*WADC TN 55-290, Pt. 2 [AD 110716]*, Jan., 1957. 86 pp.

**Effects of Acoustical Waves on the Annealing of Steels.** H. V. Fairbanks and F. J. Dewez, Jr. *ASA J.*, May, 1957, pp. 588–592. 15 refs. Experimental investigation to determine the effect of ultrasonic energy on 0.07 and 1.05 per cent carbon steels during transformation from austenite to ferrite under controlled cooling.

**Precision Steel Castings in Aircraft.** (*OTS PB 121148*, $1.75.) *Aero. Purchasing*, July, 1957, pp. 32–34, 58. Abridged. Investigation to determine why the use of casting methods is less widespread in aircraft manufacture than the economy of the method would suggest. Data and charts are presented with regard to the present situation, points of view of aircraft designers and foundries, requirements, and recommendations.

**Effects of Physical Variables on Delayed Failure in Steel.** R. D. Johnson, H. H. Johnson, J. G. Morlet, and A. R. Troiano. *USAF WADC TR 56-220*, June, 1956. 37 pp. 30 refs. Investigation to determine the effect of three specific variables, hydrogen distribution, test temperature, and prestressing, on the hydrogen-induced brittle fracture of 4340 steel in static fatigue.

**Dispersed Hard Particle Strengthening of Metals.** Nicholas J. Grant and Oliver Preston. *USAF WADC TR 56-359 [AD 118021]*, Nov., 1956. 27 pp. 37 refs. Review of various methods utilized to strengthen metals and alloys for high-temperature service by a suitable dispersion of finely divided hard particles. The theoretical aspects of the hardening and strengthening mechanism are presented and consideration is given to the problems associated with the powder metallurgy of the various processes.

**Metallography of Aluminum Powder Extrusions.** F. V. Lenel, E. C. Nelson, G. S. Ansell, and M. V. Rose. *USAF WADC TR 56-170 [AD 97155]*, July, 1956. 56 pp. 16 refs. Experimental investigation of the mechanism by which finely dispersed oxide confers strength on an aluminum matrix.

### *Metals & Alloys, Nonferrous*

**Phase and Free Energy Relationships in the System Titanium-Zirconium-Oxygen.** Michael Hoch, Patrick N. Walsh, and Yao Chiang. *USAF WADC TR 56-567 [AD 118087]*, Jan., 1957. 27 pp. 19 refs. X-ray examination of equilibrated samples, representing 50 separate compositions, at 1,500°C.

**The Strength of an Alloy Containing Zones.** A. Kelly and M. E. Fine. *Acta Metallurgica*, July, 1957, pp. 365–367. 15 refs. OSR-sponsored estimates of the stress necessary to force a dislocation through a Guinier-Preston zone in an aluminum alloy containing 2 per cent copper and one containing 13 per cent silver.

**Strain-Ageing of Aluminium-Magnesium Alloys at Temperatures Between 280° and 369°K.** A. R. C. Westwood and T. Broom. *Acta Metallurgica*, May, 1957, pp. 249–256. 12 refs. Experimental investigation of strain aging as a function of composition (0.5 to 3 per cent magnesium) and prestrain (1 to 15 per cent extension). Activation energies of 0.27 to 0.47 eV are deduced.

**Strain-Aging of Aluminum and Aluminum-Magnesium Alloys at Liquid-Air Temperatures.** A. R. C. Westwood and T. Broom. *Acta Metallurgica*, Feb., 1957, pp. 77–82. Measurements of increases in flow stress of polycrystalline superpure aluminum and aluminum-magnesium alloys following aging at liquid-air temperatures, after prior deformation at the same temperature.

**Investigation of the Effects of Hot-Cold Work on the Properties of Molybdenum Alloys.** M. Semchyshen and Robert Q. Barr. *USAF WADC TR 56-454 [AD 110708]*, Jan., 1957. 118 pp. Study to determine the relationship between strain hardening, on one hand, and mechanical properties and recrystallization temperature on the other.

**Mechanical Property, Corrosion and Welding Studies on 6066 Aluminum Alloy.** John D. Wood. *USAF WADC TR 56-99*, June, 1956. 29 pp. Investigation of the effect of salt-spray exposure on 6066-T6 sheet, and of the welding characteristics of 6066 alloys.

**Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials. I—Techniques for Measurement of Total Normal Emissivity and Reflectivity with Some Data on Copper and Nickel.** Howard T. Betz, O. H. Olson, B. D. Schurin, and James C. Morris. *USAF WADC TR 56-222, Pt. 1 [AD 110458]*, Oct., 1956. 43 pp.

**Investigation of Alloys of Magnesium and Their Properties.** G. S. Foerster, S. L. Couling, H. Baker, and R. Johnson. *USAF WADC TR 56-88 [AD 110541]*, Nov., 1956 (1957). 84 pp. 15 refs. Investigation of several alloys to determine electrical and thermal properties, the plastic deformation, and the preferred orientation of wrought alloys. The development of new wrought alloys is also discussed.

**Cumulative Fatigue Damage of Aircraft Structural Materials. II—2024 and 7075 Aluminum Alloy Additional Data and Evaluation.** Alfred M. Freudenthal and Robert A. Heller. *USAF WADC TN 55-273, Pt. 2 [AD 110491]*, Oct., 1956. 22 pp. 12 refs. Determination of the effect of randomly varying stress amplitudes, representing gust or maneuver load sequences encountered, on fatigue life of 7075 and 2024 aluminum alloys. Experiments involve testing small rotating-beam specimens subject to random time series of stress amplitudes derived from specific frequency distributions of stress amplitudes.

**An Investigation Into the Metallurgical Factors Affecting the Fatigue Properties of Some Aluminium Alloys.** R. W. George and P. J. E. Forsyth. *Gt. Brit., RAE TN Met.254*, Nov., 1956. 23 pp.

**Activation Energies for Creep of High-Purity Aluminum.** O. D. Sherby, J. L. Lytton, and J. E. Dorn. *Acta Metallurgica*, Apr., 1957, pp. 219–227. 26 refs. Experimental determination over the temperature range from 77° to 880°K. Tests involve rapid changes in temperature during creep at constant stress.

**Factors Affecting the Fluidity and Hot Cracking of Magnesium Alloys.** Appendix A—**Tabulation of Fluidity Data for Magnesium Alloys.** Appendix B—**Curves of Fluidity Versus Temperature.** Howard F. Taylor and Merton C. Flimings, Jr. *USAF WADC TR 56-453 [AD 118011]*, Jan., 1957. 84 pp. 59 refs.

**Magnesium and Its Alloys.** M. W. Mote and R. J. Jackson. *Materials in Des. Eng.*, July, 1957, pp. 115–134. Study giving the engineering properties, fabrication forms, processing characteristics, and finishing methods.

**Creep Behavior of Magnesium Alloys.** G. W. Pearsall and C. S. Roberts. *USAF WADC TR 56-456 [AD 110724]*, Dec., 1956. 28 pp. 19 refs. Establishment of an orientation relationship between precipitate and matrix in a Mg–0.7 Ce alloy, and study of the general creep behavior in Mg-Al and Mg-Th alloys and of the effects of prestrain, preferred orientation, and creep-test interruption on this behavior.

**The Effect of Microstructural Variables and Interstitial Elements of the Fatigue Behavior of Titanium and Commercial Titanium Alloys.** Appendix I—**Rotating Beam Test Specimens.** Appendix II—**Fatigue Data.** Charles B. Dittmar, G. William Bauer, and Dillon Evers. *USAF WADC TR 56-304 [AD 110726]*, Jan., 1957. 83 pp.

**Twin Intersections in Titanium.** F. D. Rosi. *Acta Metallurgica*, June, 1957, pp. 337–339. Description of the four principal types of twins found in alphatitanium.

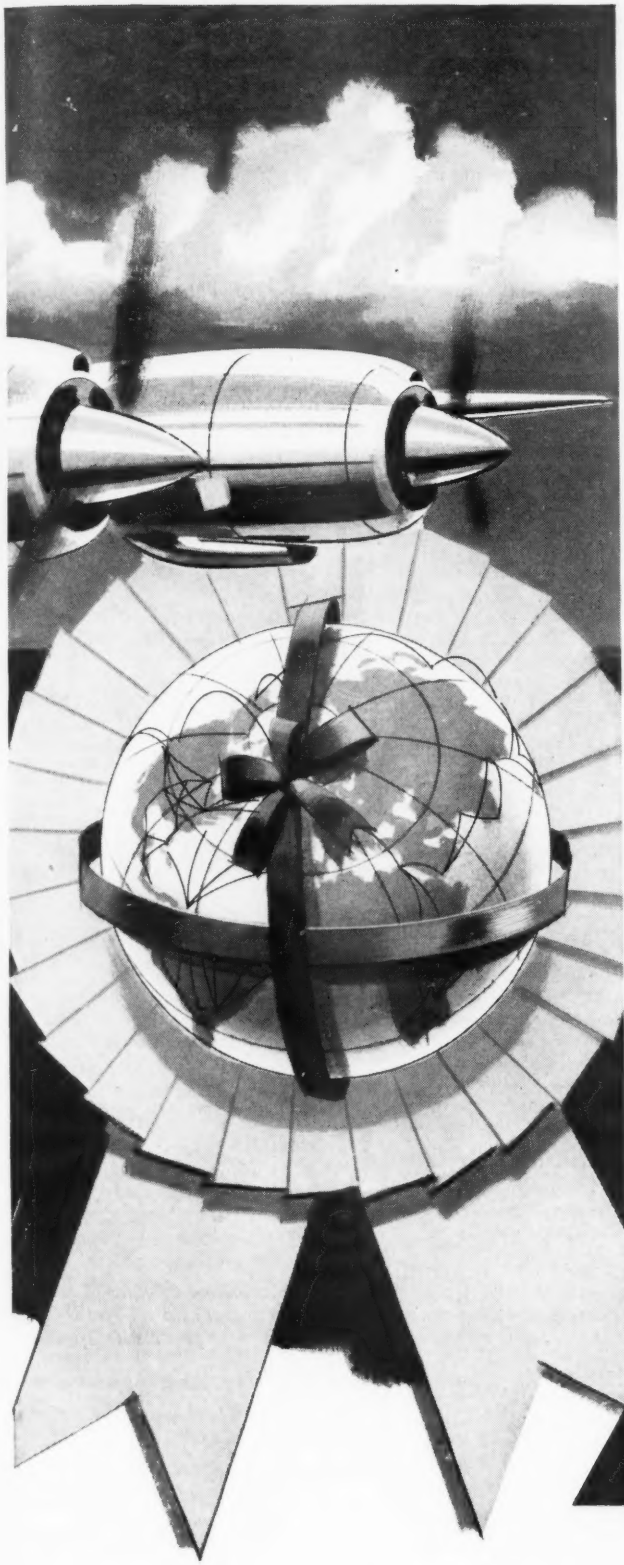
**Development of a Heat-Treatable Titanium Alloy Having Adequate Formability.** Appendix A—**Melting of Experimental Alloys.** Appendix B—**Tensile and Flow Properties of the Alloys Evaluated.** Herbert A. Robinson, Andrew J. Griest, Alvin M. Sabroff, and Paul D. Frost. *USAF WADC TR 56-545 [AD 110737]*, Jan., 1957. 71 pp. Investigation in which a series of 27 experimental alpha-beta titanium alloys are melted, forged, rolled to sheet, and evaluated as potential formable and heat-treatable sheet alloys.

**The Combined Effects of Carbon, Oxygen, Nitrogen and Hydrogen on the Properties of Titanium Sheet Weldments.** John F. Rudy. *USAF WADC TR 56-121*, June, 1956. 37 pp. Experimental determination of the physical properties of four series of alloys, for both the welded and unwelded material, by bend, tensile, and impact tests, and by hardness measurements and metallographic observations.

### *Nonmetallic Materials*

**Polymer Evaluation Handbook.** C. H. Adams, R. J. Bourke, G. B. Jackson, and J. R. Taylor. *USAF WADC TR 56-399 [AD 110557]*, Nov., 1956 (1957). 110 pp. Presentation of a system for obtaining a maximum amount of useful data on small quantities of experimental polymers; of a screening-evaluation scheme for defining the physical and chemical behavior of these materials; and of background data on the principles of evaluation, properties and measurements and their significance, the nature and behavior of polymers, and the physical characteristics of plastics in relation to each other and to other classes of materials.

**Chlorosulfonation of Silanes and Related Reactions.** C. G. Overberger and F. M. Beringer. *USAF WADC TR 56-326 [AD 110712]*, Jan., 1957. 30 pp. 25



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refs. Investigation directed toward the synthesis of polar organo-silicon monomers capable of polymerization to synthetic rubber.

**Preparation of Fluorine-Containing Compounds.** H. C. Brown, R. D. Dresdner, J. A. Wethington, Jr., and J. A. Young. *USAF WADC TR 56-234 [AD 110493]*, Nov., 1956. 21 pp. Description of the preparation, pyrolysis, or thermal reactions of certain simple fluorocarbon sulfides with fluorocarbon olefins.

**The Industrial Chemistry, Properties, and Application of Silicones.** Charles E. Reed. (*ASTM 59th Annual Meeting, Atlantic City, June 20, 1956.*) *ASTM Paper*, 1956. 47 pp. 31 refs. Discussion covering the molecular structure of silicones, the physical and chemical properties of methyl silicones related to engineering applications, the commercial development of silicone markets, silicone fluids, silicone rubber and its application for insulating wire and cable, silicones in the protective-coatings industry, release applications, the treatment of glass and ceramics, and miscellaneous applications.

**High Temperature Resistant Sealant Materials.** Leonard C. Boller, John M. Snider, John H. Emigh, Wendell Olsen, and Frank Hirosawa. *USAF WADC TR 56-155 [AD 110633]*, Dec., 1956. 59 pp. Development of a formula for a sealant compound which is unaffected by JP-5 jet fuel for a limited period of time when fuel vapor temperature is 540°F. and liquid fuel temperature is 380°F.; retains flexibility and adhesion; and withstands proof testing under flexing and pressure at the liquid and vapor fuel temperatures required.

**An Approach to the Synthesis of a Polyamide Plastic with Hydrophilic Properties.** Ezra L. Totton. *USAF WADC TR 56-117*, June, 1956. 11 pp.

**Research on Elevated Temperature Resistant Inorganic Polymer Structural Adhesives.** Harold H. Levine. *USAF WADC TR 55-271, Pt. 2 [AD 110588]*, Nov., 1956 (1957). 24 pp. Development of an inorganic adhesive stable at 800°F. with a room-temperature shear strength of 285 lb./in.$^2$. The adhesive is obtained from the ammeline-phosphorous pentoxide reaction product.

**Elevated Temperature Resistant Silicone Structural Adhesives for Metals.** Frank J. Riel, Jr., and M. Bruce Smith. *USAF WADC TR 56-533 [AD 118153]*, Mar., 1957. 36 pp. Investigation of polymers made by the reaction between polyhydroxy compounds, and a method involving synthesis of polysiloxane or polysilane resins containing tolyl groups.

**Development of Metal-Bonding Adhesive with Improved Heat Resistance.** J. M. Black and R. F. Blomquist. *USAF WADC TR 56-650 [AD 118193]*, Apr., 1957. 14 pp. Tests on an experimental phenol-epoxy resin tape adhesive, FPL-878, to determine the effects of glass and asbestos supporting mediums and of inorganic fillers on the resistance of bonded aluminum joints to aging at 500°F.

**Effect of Thickness on Strength of Epoxy and Phenolic Laminates Reinforced with Glass Fabric.** Kenneth H. Boller. *USAF WADC TR 56-522 [AD 118098]*, Mar., 1957. 17 pp. Results of tensile and compressive tests with three types of resin and two types of reinforcement in thickness. The tests show the stress at failure decreases with decreasing thickness, the magnitude of the decrease varying with the material.

**These Curves Give Fatigue Properties of Reinforced Plastics.** (*USAF WADC TR 55-389*, May, 1956.) *Materials in Des. Eng.*, July, 1957, pp. 108-111. Data on glass-reinforced laminates subjected to repeating stresses.

**Development of Thermally Stable Silicon Containing Resins.** Appendix–**Experimental Design for Study of Laminating Process.** L. W. Breed, Fred Baiocchi, and Howard W. Christie. *USAF WADC TR 57-143 [AD 118308]*, May, 1957. 47 pp. 36 refs. Investigation of possible methods for synthesizing the monomers, and application of those methods that are found suitable for preparing quantities of one pound or more, to prepare a number of compounds. A statistically designed series of experiments to study the variables effective in the formation of laminates from silicone resins and glass fiber fabric is included.

**Polyurethane Foams in Aircraft and Missiles.** Harry Gerstin. *Western Av.*, June, 1957, pp. 10-12. Discussion of the development, characteristics, formulation, and applications of the new foam.

**Waterproof Strain Gage Coating Is Easy to Use.** J. L. Garwood. *Av. Age*, July, 1957, pp. 54-57. Description of Epoxylite No. 222, a flexible epoxyresin/Thiokol[2] liquid polymer that is unaffected by water.

**Effect of Moisture Sorption on Weight and Dimensional Stability of Alkyd-Isocyanate Foam Core.** V. C. Setterholm and E. W. Kuenzi. *USAF WADC TR 56-86 [AD 97289]*, Sept., 1956 (1957). 26 pp. Tests on foam cores of varying densities subjected to immersion in water and exposure to high humidity for 60 days.

**Tensile Strength of Plastics Below the Glass Temperature.** F. Bueche. *J. Appl. Phys.*, July, 1957, pp. 784-787. Presentation of a theory which describes the strength properties of plastics in the glassy state. The times taken for two plastics, polystyrene and polyethyl methacrylate, to break under various constant loads are reported for both glassy and rubbery states.

**New Silicone Rubber Combines Tensile Strength and Heat Resistance.** J. C. Caprino and Richard M. Savage. *Av. Age*, July, 1957, pp. 58-63 ff. Description of General Electric's material 81716, which has a very high tensile strength when cured for short periods at high temperature and still has the strength of typical silicone rubber at around 480°F.

**Research on the Synthesis of Polar Silane Monomers.** Robert M. Silverstein, Leon Goodman, and Allen Benitez. *USAF WADC TR 56-530 [AD 110717]*, Jan., 1957. 21 pp. Development of a process to synthesize polymerizable, polar silane monomers for use as precursors or modifiers for improved silicone rubbers. Gums are prepared from these monomers, homopolymerized or copolymerized with dimethylsilicone oils, such that the copolymer can be compounded to produce suitable silicone elastomers.

**The Preparation and Properties of Some New Fluorine-Containing 1,2-Epox-**


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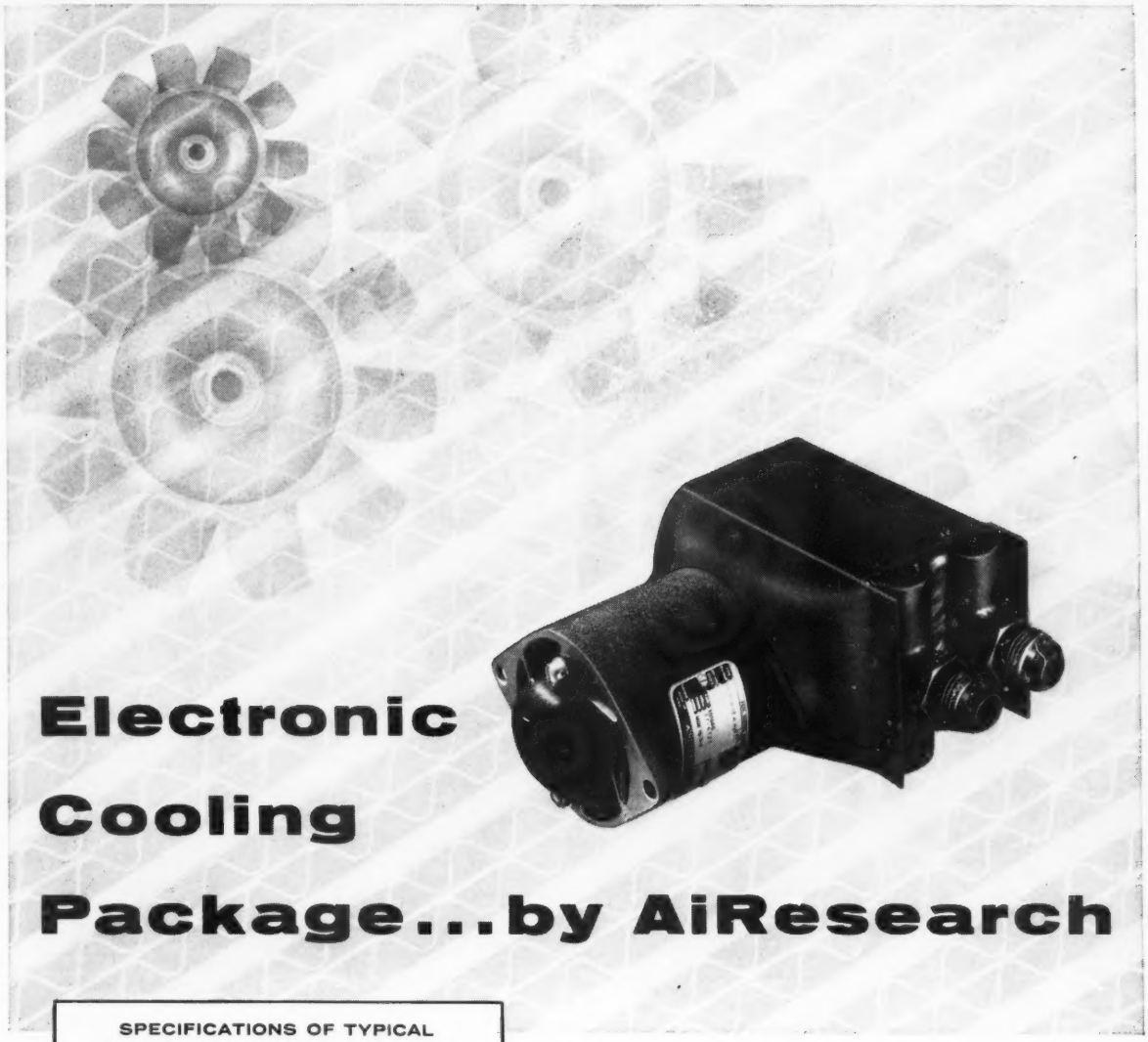

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| Fan Air Inlet Pressure | 18 PSIA |
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| Heat Exchanger Pressure Drop | 1.0 inches water |
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| Liquid Flow | 0.4 GPM |
| Heat Rejection* | 300 Watts |
| Fan Power | 30 Watts, 110 V., single phase, 400 cycle |
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**ides.** D. A. Rausch and A. M. Lovelace. *USAF WADC TR 56-94*, May, 1956. 6 pp.

**The Fluoro-Elastomers: Latest Weapon Against Heat and Fluids.** Malcolm W. Riley. *Materials in Des. Eng.*, July, 1957, pp. 90–94. Presentation of data on important features of five fluoro-elastomers. This data includes manufacturers, mechanical properties, heat resistance, fluid resistance, and applications.

## Mathematics

**On Integral Relations Involving Products of Spheroidal Functions.** Nicholas Chako. *J. Math. & Phys.*, Apr., 1957, pp. 62–73. USAF-supported analysis.

**Modified Relaxation Method for Eigenvalue Problems.** W. W. Clendenin. *J. Math. & Phys.*, Apr., 1957, pp. 74–81. OSR-sponsored description of a numerical method for solving a one-dimensional Schroedinger equation.

**A Comparison of the Original and Revised Simplex Methods.** Harvey M. Wagner. *Oper. Res.*, June, 1957, pp. 361–369. 13 refs. Application of only the rudiments of matrix algebra in an outline of the procedure for the revised simplex method of linear programing.

**Lommel-Type Integrals Involving Three Bessel Functions.** Henry E. Fettis. *J. Math. & Phys.*, Apr., 1957, pp. 88–95.

**Errors in the Solution of Integral Equations.** Parry Moon and Domina Eberle Spencer. *J. Franklin Inst.*, July, 1957, pp 29–41. Development of a method for solving integral equations by obtaining an analytical solution and adding to it the solution of an auxiliary integral equation. Simple equations are derived for the magnitude of the error caused by approximating the kernel, and the results are applied to interflections in cylindrical blackbodies.

**Computational Aspects of Dynamic Programming.** Stuart E. Dreyfus. *Oper. Res.*, June, 1957, pp. 409–415. Isolation of several computational difficulties characteristic of dynamic programing, examination of present techniques, and suggestion of areas for further developments.

**Fractional Factorial Experiment Designs for Factors at Two Levels.** *U. S., NBS Appl. Math. Ser. 48*, Apr. 15, 1957. 85 pp. 18 refs. $0.50. Fractional replicate designs for $n = 5(1)16$ and for a range of $p = 1, 2, 3, 4, 5, 6, 7, 8$, constructed such that the $2^{n-p}$ treatments are divided into $2^s$ blocks (columns) containing $2^{n-p-s}$ treatments each.

**Mathematical Tables—A Bibliography.** Charles R. Sexton. *Prod. Eng.*, July, 1957, pp. 183–194.

**Vectors Simplify Tolerance Analysis.** W. Hanka. *Prod. Eng.*, July, 1957, pp. 195, 196. Graphical approach to the analysis of tolerances for nonparallel, nonrectangular dimensions. Includes three sample problems.

**Multiple Layer Potentials and the Dirichlet Problem for Higher Order Elliptic Equations in the Plane. I.** Shmuel Agmon. *Commun. on Pure & Appl. Math.*, May, 1957, pp. 179–239. 17 refs. ONR-supported application of the Newmann-Fredholm method which tries to represent the desired solution of the Dirichlet problem by a double layer potential, reducing the problem to a Fredholm-type integral equation.

**Four-Place Logarithms to the Base 2 of Three-Digit Numbers.** Earl A. Alluisi and Ilse B. Webb. *USAF WADC TN 56-499 [AD 110581]*, Dec., 1956 (1957). 4 pp. Tables for the 3-digit numbers between 1.00 and 9.99.

**On the Analyticity of the Solutions of Linear Elliptic Systems of Partial Differential Equations.** C. B. Morrey, Jr., and L. Nirenberg. *Commun. on Pure & Appl. Math.*, May, 1957, pp. 271–290. 12 refs. ONR-supported study of strongly elliptic equations in a domain with analytic boundary to prove the analyticity at the boundary of solutions with analytic Dirichlet data. It is also shown how the method of proof yields a new derivation of analyticity of solutions of general analytic elliptic systems at interior points of a domain.

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**Theory of Slipping and Periodic Sticking of Solid Bodies (Friction Self-Oscillation of the First Kind). I—General Condition for Occurrence of Sticking.** B. V. Deriagin, V. E. Push, and D. M. Tolstoi. *Soviet Physics - Tech. Physics*, No. 6, 1957, pp. 1,299–1,312. Translation. Includes discussion of the physical nature of the phenomenon, quantitative treatment of an elastically-coupled slide moving over a plane, and calculation of the dependence of

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**Podstawy Klasyfikacji Strukturalnej Mechanizmów Płaskich.** Adam Morecki. *Arch. Budowy Maszyn*, No. 2, 1957, pp. 249–265. In Polish, with summaries in English and Russian. Classification of mechanisms with kinematic pairs of the fifth class.

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**Numerical Weather Prediction.** R. Pfeffer and N. Phillips. *Appl. Mech. Rev.*, July, 1957, pp. 279–281. 58 refs. Discussion of methods for predicting weather, based on laws of physics as applied to the atmosphere.

## Military Aviation & Armament

**Mission Bullseye: The Story of the MD-9 Airborne Tests.** Helen Pitchersky. *Arma Eng.*, May-June, 1957, pp. 6–9. Description of the flight test of Arma's MD-9 Fire Control System.

**Air Force Relies on Modified Weapon System Procurement Policy.** David H. Baker. *SAE J.*, July, 1957, pp. 40–42. Abridged. Discussion which reveals that for missiles the prime contractor handles all procurement. On manned aircraft, the prime contractor handles all procurement in the development stage. In the production stage the government procures and furnishes much of the equipment going into the airframe.

**A Hand-Computation Determination of Kill Probability for Weapons Having Spherical Lethal Volume.** H. W. Lilliefors. *Oper. Res.*, June, 1957, pp. 416–421.

## Missiles

**Britain's Guided Weapon Industry.** F. T. Meacock. *The Aeroplane*, June 28, 1957, pp. 908–917. Review of the missile activities of British aircraft companies. Includes a description of production weapons, and of weapon power plants.

**Flight Testing of Guided Missiles.** Milton Kuska. *IAS Natl. Summer Meeting, Los Angeles, June 17–20, 1957, Preprint 748.* Members, $0.35; nonmembers, $0.75. 8 pp. Discussion of the Snark flight-test program which was divided into four phases: (1) aerodynamic and performance tests, (2) armament tests, (3) missile-guidance tests, (4) full weapon-systems demonstration. Discussion includes the vibrational environment and the pilots' role in testing.

**Factors in Missile Design.** George W. Jeffs. *Western Av.*, June, 1957, pp. 6–8. Discussion of the weapons system concept as it applies to the selection and design of a missile to meet specific requirements. Study shows how the particular missile type, trajectory, means of controlling temperature, configuration, and booster are all selected and integrated.

**On the Normal-Force Distribution of a Cone-Frustum Body at Supersonic Speeds.** William Dru Murphree. *J. Aero. Sci.*, Sept., 1957, pp. 710, 711. Presentation of a method for calculating the aerodynamic characteristics of conical-nosed bodies, particularly those followed by frustum afterbodies, as a means of selecting a missile configuration. Experimental data and the results of theoretical calculations for a cone-frustum body are presented for a Mach Number range of 1.54 to 4.38.

## Navigation

**Landing Forecasts for London Airport.** J. D. Proctor. *Inst. Navigation J.*, July, 1957, pp. 291–299. Investigation into the operational safety of landing forecasts (TAFs) as used to decide whether or not an aircraft will be able to make a safe approach and landing at its destination.

**Cytac—A Multi-Purpose Precision Navigation System.** Wilbert P. Frantz. *Sperry Eng. Rev.*, May-June, 1957, pp. 2–6. Description of a radio navigation system which provides long range and high accuracy for both air and surface travel. The principles of operation are discussed, and range and accuracy data from field evaluation studies are given along with proposed station arrangements to provide coverage for the U.S. and North Atlantic shipping lanes.

**Route Analysis and Flight Planning with Isotachs.** P. G. Powell. *Inst. Navigation J.*, July, 1957, pp. 264–270. Description of the development by Trans-Canada Air Lines of two new templates to enable optimum use of the new contour-isotach charts.

**Position Reporting for Advisory Air Routes.** Appendix—**Off-Track Position Reporting.** J. L. Cowan. *Inst. Navigation J.*, July, 1957, pp. 284–290.

## Nuclear Energy

**Contributions of Optical Methods to Nuclear Physics.** G. Breit. (*Internatl. Comm. Optics, 4th Cong., Boston, Mar. 28–Apr. 3, 1956.*) *J. OSA*, June, 1957, pp. 446–459. 79 refs. OSR-supported general review of developments in nuclear physics which have resulted from the application of optical methods to the study of nuclei. Some of the items discussed are the coupling of electron system to nuclear spin; the electron-nuclear volume and shape effect; the hyperfine structure of the isotopes of hydrogen; distribution of nuclear-magnetic, isotope-shift, and quadrupole moments; and the bearing of the latter on nuclear models.

**Fusion Reactors Promising Nuclear Powerplants.** Leo Seren. *Av. Age*, July, 1957, pp. 42–49 ff. Discussion of the advantages of fusion over fission reactors, deuterium and tritium as reactor fuels, and the problems associated with fusion reactors and possible means for overcoming them.

**On Radiation-Induced Irreversible Changes in Metals and Alloys and the "Temperature-Spike" Concept of Radiation Damage.** Roger Chang. *Acta Metallurgica*, May, 1957, pp. 275–280. 13 refs. Calculation of the temperature distribution in the immediate neighborhood of a primary knockon between fast neutrons and a heavy metal, and correlation of the results with the induced irreversible changes in metal.

## Parachutes

**A Study of the Effects of Chemicals on the Strengths of Nylon and Dacron Parachute Fabrics.** David M. Cates. *USAF WADC TR 56–288 [AD 110558]*, Nov., 1956 (1957). 217 pp. Investigation of the effect of organic solvents and solutions of inorganic substances on the strength of fabrics. The fabrics are exposed to each of the reagents and then aged under different conditions for a period of six months. Breaking-strength tests are made at monthly intervals.

**Research and Development of Abrasion Resistant Treatments for Nylon Webbings.** George Thomson, Joseph S. Panto, Myron J. Coplan, and Ernest R. Kaswell. *USAF WADC TR 56–151*, June, 1956. 69 pp. Investigation to obtain a method for improving low-temperature flexibility and heat-aging resistance, as well as abrasion resistance.

## Photography

**Fiber Optics. III—Field Flatteners.** N. S. Kapany and R. E. Hopkins. *J. OSA*, July, 1957, pp. 594–598. Method of field flattening using a bundle of transparent fibers. Different optical arrangements of field flatteners are proposed and their relative merits are investigated.

**Strato-Lab Balloon Photography.** Eugene P. Griffin. *Photogrammetric Eng.*, June, 1957, pp. 582–587. Description and results of limited photogrammetric instrument tests made during the first known attempt to obtain and use mapping photography taken from an altitude of 89,000 ft. in a free-flight, unmanned, plastic balloon.

## Physics

**Application of Luminescence Changes in Organic Solids to Dosimetry.** James H. Schulman, Howard W. Etzel, and James G. Allard. *J. Appl. Phys.*, July, 1957, pp. 792–795. 10 refs. OSR-supported study of the degradation of photoluminescence in anthracene and in naphthalene under gamma-ray and electron irradiation. The employment of the resultant effects for dosimetry is discussed.

**Vapor Pressure Data for the More Common Elements.** Richard E. Honig. *RCA Rev.*, June, 1957, pp. 195–204. 13 refs. Selection, tabulation, and plotting of the most recent data available on vapor pressures, melting and boiling points, and heats of sublimation. Vapor pressure data, presented graphically as plots of log $p$ (mm. Hg) vs. log $T$ (°K.), and the absolute temperatures for fixed pressures are tabulated.

**Low-Energy Elastic Scattering of Electrons by Oxygen and Nitrogen.** P. Hammerling, W. W. Shine, and B. Kivel. *J. Appl. Phys.*, July, 1957, pp. 760–764. ARDC-supported calculation of oxygen and nitrogen cross sections for elastic electron scattering. The electron atom interaction potential is formed from (1) the Hartree potential of the undisturbed atomic core, (2) an exchange term, and (3) a polarization term.

**Thermoelectric Power and Resistivity of Solid and Liquid Germanium in the Vicinity of Its Melting Point.** C. A. Domenicali. *J. Appl. Phys.*, July, 1957, pp. 749–753. 14 refs. Measurement of the thermoelectric power of germanium against platinum between room tempera-

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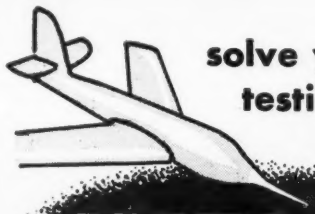

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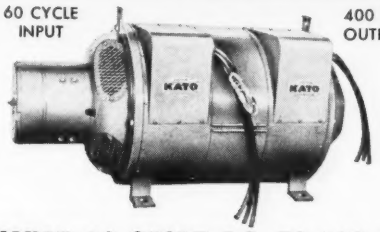


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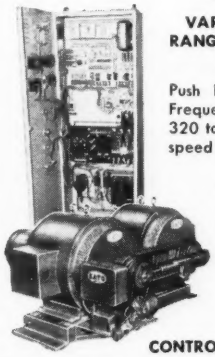

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ture and 1,030°C. Five specimens are studied in the solid phase and two in the liquid phase.

**High Perveance Beams From Arc Cathodes.** Charles W. Hartman. *USAF WADC TR 57-238 [AD 118298]*, May, 1957. 32 pp. Description of experiments directed toward extracting high-voltage electron beams from d.c. and pulsed-arc plasmas.

**Application of Balanced Potentials Potentiometric Argentometry to Elementary Organic Microanalysis.** R. Levy. (*Bul. Soc. Chim. France*, No. 3, 1956, pp. 497–527.) *Gt. Brit., RAE Lib. Transl. 641*, Apr., 1957. 48 pp. 38 refs.

**Study of Optical Diffraction Images at Microwave Frequencies.** M. P. Bachynski and G. Bekefi. (*OSA Spring Meeting, Philadelphia, Apr., 1956.*) *J. OSA*, May, 1957, pp. 428–438. 26 refs. USAF-supported experimental investigation of the intensity distribution in the region of the focus of microwave lenses. Most of the measurements are presented in the form of intensity contours in planes both containing the principal ray and lying perpendicular to it. Includes some preliminary investigations of the electromagnetic field in the vicinity of the focus.

**"Electro-Gravitics": What it is—or Might be.** A. V. Cleaver. *Brit. Interpl. Soc. J.*, Apr.-June, 1957, pp. 84–94. Review of current trends in antigravity research.

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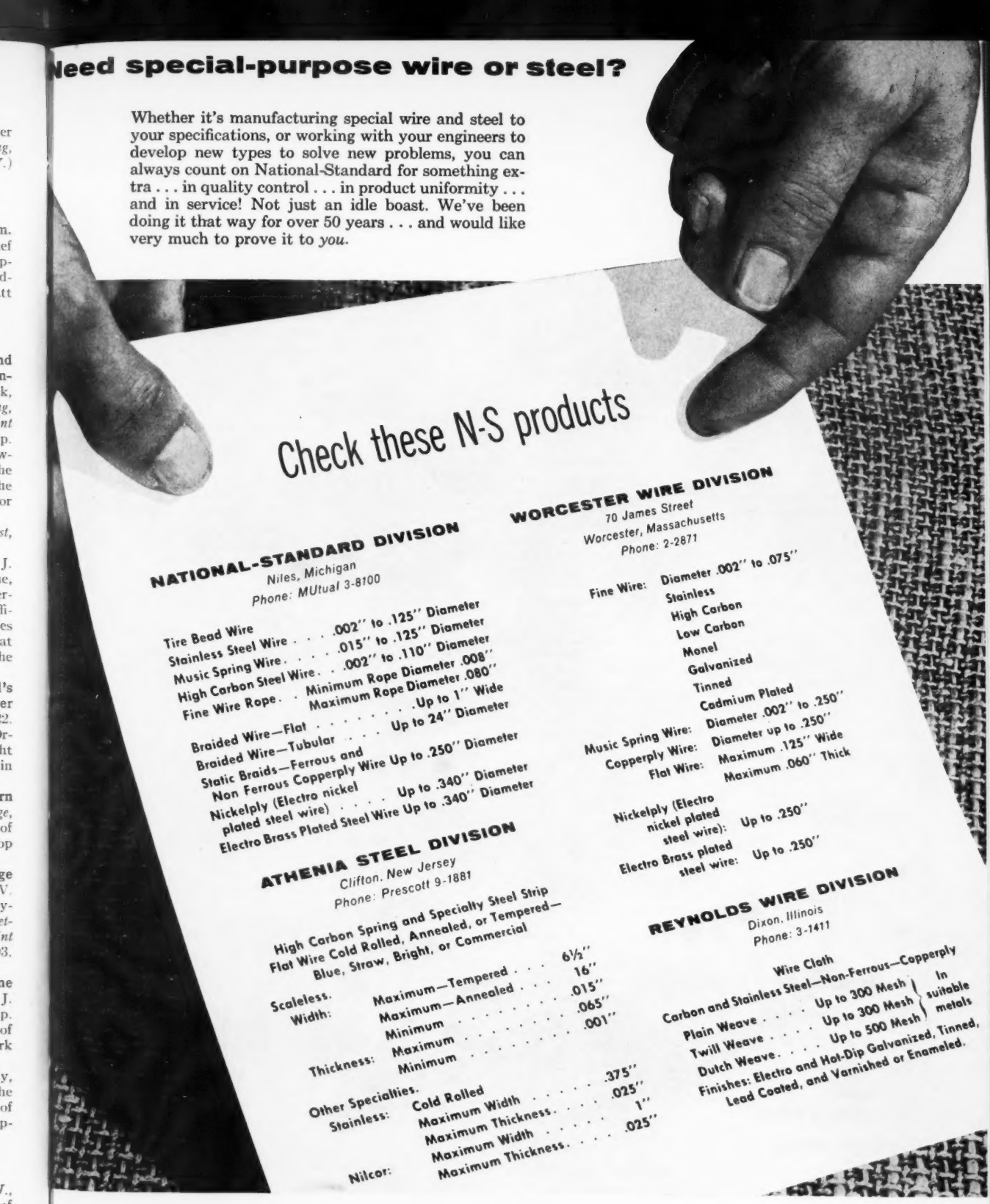

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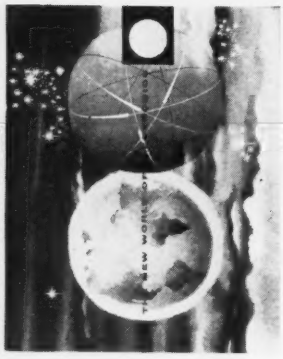

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**Unsteady Thermodynamic Processes.** A. P. Hatton. *The Engr.*, June 21, 1957, pp. 949–951. Analysis of unsteady flow using the concept of a control volume. Application is made to an adiabatic flow of gas into a low-pressure region and inflow to a tank from a steam main.

**Wrzenie Pęcherzykowe Cieczy w Warunkach Konwekcji Swobodnej.** Bogumił Staniszewski. *Arch. Budowy Maszyn*, No. 2, 1957, pp. 187–220. 11 refs. In Polish, with summaries in English and Russian. Derivation, on the basis of experimental data, of a relation for calculating the coefficient of heat absorption in the bubble boiling of a liquid under free-convection conditions. Relations are also established for calculating the critical values of the heat stream tension.

**Plane Waves in a Thermoelastic Solid.** H. Deresiewicz. *ASA J.*, Feb., 1957, pp. 204–209. 10 refs. ONR-supported investigation of the properties of the two

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dilatational motions existing in an isotropic thermoelastic solid. Relations are given expressing the variation, in each, of phase velocity, amplitude attenuation, and specific loss with impressed frequency.

### *Combustion*

**Propagation of a Free Flame in a Turbulent Gas Stream. Appendix A, B—Turbulence and Sound Instrumentation and Analysis. Appendix C—Photomultiplier Instrumentation. Appendix D—Calculation of Flame Speed from Scurlock-Grover Analysis.** William R. Mickelsen and Norman E. Ernstein. *U.S., NACA Rep. 1286*, 1956. 26 pp. 36 refs. Supt. of Doc., Wash., $0.30. Measurement of effective flame speeds by photographic, ionization-gap, and photomultiplier-tube methods.

**Propagation of Detonations and Deflagrations in Gaseous Mixtures.** N. Manson. (*France, ONERA, Inst. Franc. Petroles Rep. (Div. 1)*, 1947.) *Gt. Brit., MOS TIL/T4693*, Nov., 1956. Presentation of a dynamic adiabatic curve for both an inert gas and a mixture capable of reacting at high temperatures.

**Flame Stabilization by Means of Obstacles.** G. Matton. (*La Recherche Aéronautique*, Mar.-Apr., 1957, pp. 11–17.) *Engr. Dig.*, June, 1957, pp. 251–254. 10 refs.

**Flame Propagation Rates; Chemical Nature of Attachment Surface.** Leon Lapidus, J. B. Rosen, and R. H. Wilhelm. *Ind. & Eng. Chem.*, July, 1957, pp. 1,181–1,186. 14 refs. OSR-supported presentation of an approach to the basic phenomenon of flame propagation which introduces a self-consistent theoretical model leading to quantitative values of surface recombination relative to platinum surfaces.

### *Heat Transfer*

**Heat Transfer by Transverse Flow of a Two-Phase Stream Over a Hot Cylindrical Tube.** P. Z. Alimov. *Soviet Physics-Tech. Physics*, No. 6, 1957, pp. 1,264–1,277. 11 refs. Translation. Experimental investigation of heat transfer from surfaces of heated metallic cylinders placed transversely in a stream of air containing minute droplets of water. Qualitative relationships are obtained, at low air speeds, for each of the two heat-exchange states which are shown to exist and to depend on the temperature of the steamed surface.

**Conduction of Heat in a Finite Slab of Three Layers.** Vaclov Vodička. *Arch. Budowy Maszyn*, No. 4, 1956, pp. 319–331. In Polish and in English, with Russian summary. Presentation of a calculation using the Laplace transformation method. A symmetrical problem is analyzed as a special case.

**Przewodzenie Okresowo Zmiennego Strumienia Cieplnego w Ośrodkach Wielowarstwowych.** Václav Vodička. *Arch. Budowy Maszyn*, No. 1, 1957, pp. 63–73. In Polish, with summaries in English and Russian. Development of a method for analyzing the conduction of periodic heat flow in multilayer bodies. A common procedure is given for treating all three fundamental cases—bodies with plane, cylindrical, and spherical boundaries—and theoretical conclusions are applied to the case of a sphere. Analogies to the theory of a passive, four-terminal network are shown.

## VTOL & STOL

**Evaluation of VTOL Systems Suitable for Transport Aircraft.** W. Z. Stepniewski and Joseph Mallen. (*IAS 25th Annual Meeting, New York, Jan. 28–31, 1957, Preprint 724.*) *Aero. Eng. Rev.*, Sept., 1957, pp. 60–68.

**Douglas Turboprop Uses Double-Slotted Wing Flaps for STOL Missions.** Irwin Stambler. *Av. Age*, July, 1957, pp. 34–41 ff. Description of the proposed Douglas 1906A aircraft to incorporate low wing loading, high lift flaps, reverse propeller thrust, and lift spoilers.

## Wind Tunnels & Research Facilities

**Beitrag zur Geschwindigkeitskorrektur in Windkanälen bei kompressibler Unterschallströmung.** Georg Schmitz. *ZFW*, June, 1957, pp. 169–172. In German. Extension of von Baronoff's calculations, regarding the change of the free-stream velocity in a wind tunnel with fixed walls, to include the case of an open-jet wind tunnel.

**Bangalore Supersonic Research.** D. M. Rao. *Indian Skyways*, May, 1957, pp. 45–49. Description of the wind-tunnel facilities of the High Speed Aerodynamics Laboratory of the Indian Institute of Science.

**Electronic Calibration Center.** *Missile Des. & Devel.*, July, 1957, pp. 12, 13. Description of the National Bureau of Standards Center to calibrate interlaboratory secondary standards for such quantities as voltage, power, and impedance, against master standards to be maintained at the center.

**Apparatus for the Production of Air with Controlled Humidity.** Bjorn-Ivar Stafsing. (*Sweden, Svensk Pappers Tidning*, No. 10, 1955, pp. 392–394.) *Gt. Brit., MOS TIL/T4776*, Apr., 1957. 5 pp. Description of an apparatus which produces 0.5 to 1.0 liter/min. of air with a relative humidity of from 30 to 95 per cent. No direct measurement of relative humidity is required, only the measurement of two temperatures.

**Brief Description of the R.A.E. Intermittent Supersonic Wind Tunnel Plant.** K. G. Winter. (*Gt. Brit., RAE TN Aero. 2459*, June, 1956.) *Gt. Brit., ARC CP 336*, 1957. 15 pp. BIS, New York, $0.45.

**Missiles at Hypersonic Velocities.** *Missile Des. & Devel.*, July, 1957, p. 14. Discussion of equipment and research projects, the NACA Ames Laboratory, and the Cornell Aeronautical Laboratory.

**Tables of Characteristics Slopes for Use in the Design of Nozzles for Supersonic Wind Tunnels.** K. G. Winter. (*Gt. Brit. RAE TN Aero.2444*, May, 1956.) *Gt. Brit. ARC CP 337*, 1957. 10 pp. BIS, New York, $0.54.

**Thermodynamic Study of a Roots Compressor as a Source of High-Temperature Air. Appendix A—Verification of Equations. Appendix B—Evaluation of Stanton Number.** Clarence B. Cohen, Richard R. Woollett, and Kenneth C. Weston. *U.S., NACA TN 4025*, June, 1957. 34 pp.

**On Ménard Inserts in Supersonic Nozzles.** J. L. Amick, S. A. Harrington, and H. P. Liepman. *J. Aero. Sci.*, Sept., 1957, pp. 707, 708. Development of a method for using Ménard inserts as a simple and economical technique of changing the Mach Number of a set of fixed nozzle blocks for the 19 × 27.5-in. wind tunnel of the Ordnance Aerophysics Laboratory.

**Nozzle and Contraction Shapes of the R.A.E. 3 ft. × 3 ft. Supersonic Wind Tunnel.** A. Stanbrook. *Gt. Brit., RAE TN Aero.2444*, Feb., 1957. 9 pp. Presentation of ordinates of the contraction liner and the solid liners.

**Metody Wizualne Stosowane Przy Badaniu Ośrodków o Niejednorodnym Pozkładzie Gęstości.** Kazimierz Brodowicz. *Tech. Lotnicza*, Mar.-Apr., 1957, pp. 52–57. In Polish. Development of visualization methods used in the research of nonuniform density media.

**Loads on a Model During Starting and Stopping of an Intermittent Supersonic Wind Tunnel.** K. G. Winter and C. S. Brown. (*Gt. Brit., RAE TN Aero.2453*, May, 1956.) *Gt. Brit., ARC CP 335*, 1957. 17 pp. BIS, New York, $0.54.

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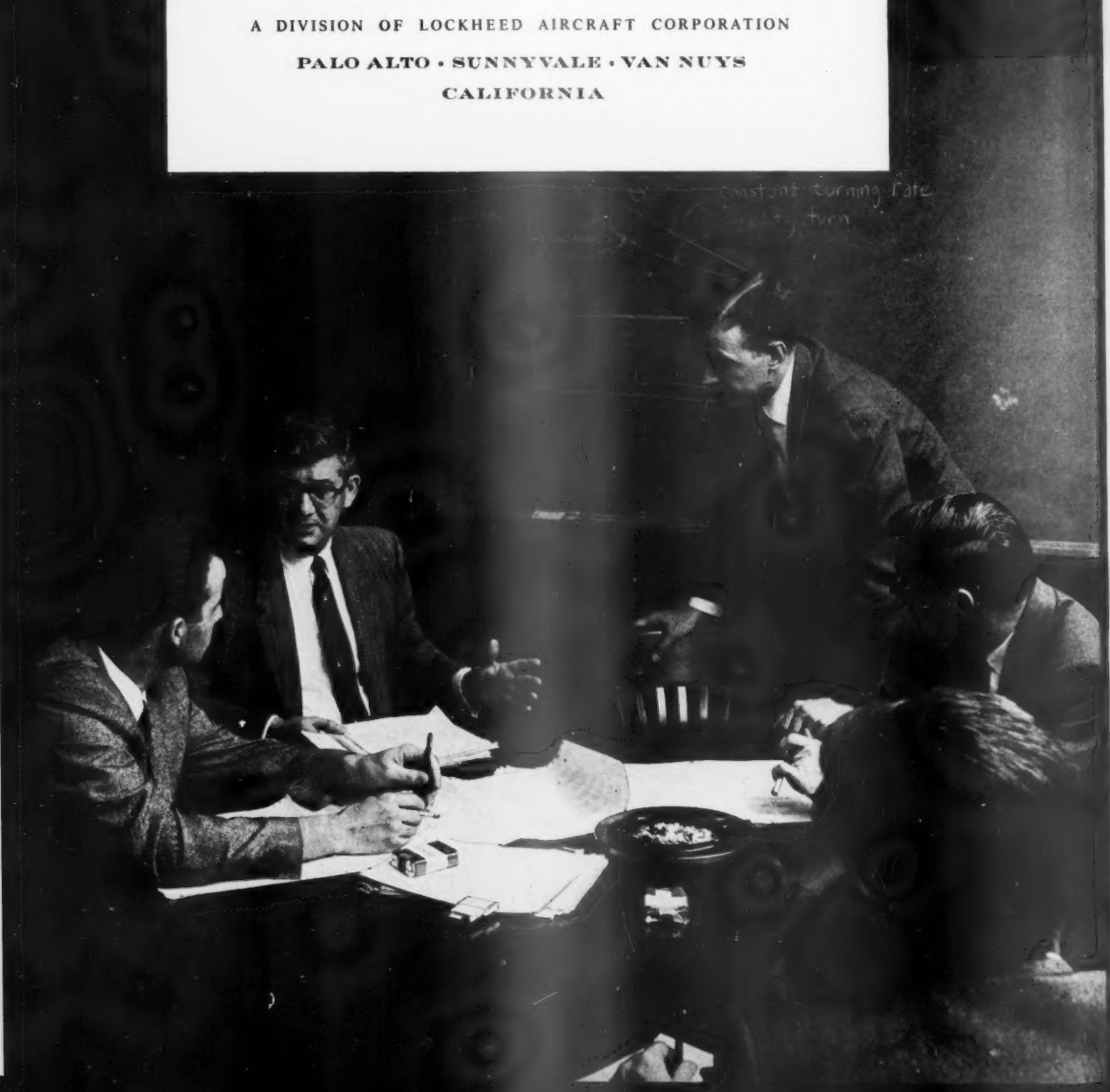

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**1957 Heat Transfer and Fluid Mechanics Institute;** Held at California Institute of Technology, June 19–21, 1957. Stanford, Calif., Stanford University Press, 1957. 439 pp., illus., diagrs., tables. $8.50.

The 1957 Heat Transfer and Fluid Mechanics Institute is the tenth of a series initiated in 1948 for the purpose of making available in the West a program on current advanced fundamental research in heat transfer and fluid mechanics. This year's papers reflect more than ever the recent rapid development of high-speed research including heat-transfer problems at extreme temperatures.

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**Aerodynamik der reinen Unterschallströmung (The Aerodynamics of Pure Subsonic Flow).** F. Dubs. Basel, Verlag Birkhauser, 1955. 225 pp., figs. 22 Sw. fr. In German.

The author, a flight engineer and Chief Instructor, Mechanical and Technical Department, Zurich Trade School, has written this book for students, pilots, engineers, and others requiring a treatment of the subject that is thorough and comprehensive, yet simple in comparison with most of the highly specialized textbooks available. Emphasis is put on the physical explanation of the phenomena and the devices employed; mathematics is introduced only when necessary to further this purpose. The volume is profusely illustrated with diagrams and charts; it contains a brief bibliography and a subject and name index.

*Contents:* (1) The Atmosphere. (2) Laws of Flow. (3) Types of Flow. (4) Flow Pictures. (5) The Boundary Layer. (6) Means of Preventing Transition. (7) Subsonic Wind Tunnels. (8) The Magnus Effect. (9) The Airfoil. (10) Airfoil Shape and Polar. (11) Residual Drag. (12) Interference Drag. (13) Air Brakes. (14) The Aircraft Polar.

## AERONAUTICS, GENERAL

**Bulletin de l'Association Technique Maritime et Aéronautique, No. 55, Session de 1956.** Paris, Association Technique Maritime et Aéronautique, 1956. 902 pp., illus., figs. In French.

*Partial Contents:* The S.E. 210 Caravelle Airplane, J. Dor. Arithmetic Calculators in the Air Force and the Navy, H. Boucher. Contributions to the Subject of the Linearized Potential with Free Surface Applied to the Study of Hulls, R. Guilloton. Limits in the Application of Lifting Line Theory to the Calculation of Aircraft Wings Provided with Spoilers, A. Fauquet. Analysis of the Theoretical Operation of the Gas Turbine with the Aid of Graphic Representation, L. Poincaré. Combustion in Aviation Jet Engines (Turbines and Ramjets), Th. Seifferlein. Flush or Cavity Antennas in Aircraft, F. Babin. Azimuth-Distance Methods for Medium-Range Navigation in Civil Aviation, J. J. Villiers. Radiogoniometry with Decimeter Waves Applied to Aeronautical Radio Navigation, A. Gras and J. Lochard. Flutter Tests of a Model Wing, R. Landais. Influence of Actuator Imperfections (Play, Elasticity, Friction) on Control System Effectiveness, M. Nicolas.

## AIRCRAFT

**Cours d'Aérotechnique (Course in Technical Aeronautics).** G. Serane. 2nd Ed. Paris, Dunod, 1957. 300 pp., illus., figs. 1,950 fr. In French.

A comprehensive text for aviation students, flying personnel, and technicians—and for those studying aerodynamics and the mechanics of flight in preparation for piloting and navigation licenses. The author is an engineer with Sud-Est Aviation and formerly was in charge of training flying personnel for Air France.

*Contents:* Fluids at Rest. Fluids in Movement. Resistance of the Air; Tests (Wind Tunnel). Studies of Simple Bodies in Flow. The Wing. The Aircraft; Models. Power Plants. The Mechanics of Aircraft Flight. Equilibrium of the Aircraft Around its Center of Gravity. Aircraft Performance. The Hydroairplane. Principal Flight Instruments.

## ATMOSPHERIC ELECTRICITY

**Atmospheric Electricity.** J. Alan Chalmers. London, New York, Pergamon Press, 1957. 327 pp., illus., diagrs. $10.

A salient feature of this detailed discourse on electricity in the atmosphere is the 31-page bibliography that cites nearly 500 references concerned with electrical and meteorological phenomena. Certain topics, such as earth currents, exploration of the ionosphere, and the aurora, have been omitted as irrelevant to the general problems of the subject. Dr. Chalmers is Senior Lecturer in Physics in the Durham Colleges, University of Durham.

*Contents:* (1) Historical Survey. (2) General Principles and Results. (3) The Ions in the Atmosphere. (4) The Earth's Vertical Potential Gradient. (5) The Conductivity of the Air. (6) The Air-Earth Conduction Current. (7) Point-Discharge Currents. (8) Precipitation Currents. (9) The Transfer of Charge. (10) The Thunder Cloud. (11) The Lightning Discharge. (12) The Separation of Charge. (13) Conclusion. Appendix I. Appendix II. References. Index.

## BALLISTICS

**Waffe und Wirkung bei der Fliegerabwehr; Wahrscheinlichkeitstheoretische Studie zur vergleichenden Beurteilung von Waffen (Antiaircraft Armament and its Effectiveness; A Study Using Probability Theory for the Comparative Evaluation of Weapons).** Hans Brändli. Basel, Birkhäuser Verlag, 1956. 91 pp., figs. 26-Sw. fr.

Various tests have been applied for the comparison of two antiaircraft weapons of different configuration and different caliber with respect to their efficiency in hitting and shooting down aircraft. The author's aim is to handle this problem in greater depth than has been done in the available studies and to bring this complex subject into greater clarity. In general, his treatment is concerned with the comparison of two weapons of small or medium caliber, which are activated by some type of control device and gun drive. The study is confined to weapons that attack their targets by series or sequence fire and is not considered applicable to barrage fire, which requires a different approach.

The author, Dr. Brändli, is Director, Contraves AG, of Zurich, who manufacture antiaircraft systems and controls, guided missiles, and various types of electronic and computing devices.

## CONTROL SYSTEMS

**Basic Automatic Control Theory.** Gordon J. Murphy. Princeton, N.J., D. Van Nostrand

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Statements and opinions expressed in Book Reviews are to be understood as individual expressions and not necessarily those of the Institute.

Company, Inc., 1957. 557 pp., diagrs., tables. $9.00.

This survey of the most recent concepts of automatic control theory describes the analysis and synthesis of linear control systems having fixed, lumped parameters and subject to input commands and disturbances that can be specified with certainty. To render the book useful for instructional purposes, the various topics discussed are presented in the most logical order. These include applications of practical systems; physical analogies and the characteristics of common control-system components; a treatment of the Laplace transform; a presentation of the generalized transfer-function concept and signal-flow diagrams; a definition of system types, which details the extension of the transfer-function concept to carrier systems; an explanation of stability and the frequency-response techniques of analysis and synthesis; time response of control systems, using root loci to allow swift determination of the system's behavior; the correlation of the frequency-response and time-response methods, showing the advantages and disadvantages of each; and the components and operations of analog computers.

The text has evolved from lecture notes offered by the author, Assistant Professor of Electrical Engineering, University of Minnesota, to senior and first-year graduate students in engineering and physics.

**Servosystems Laboratory Manual.** New Hyde Park, N.Y., Servo Corporation of America, 1957. 32 pp., illus., diagrs. $1.50.

Seven integrated, class-tested experiments are used to furnish an introductory laboratory course in servomechanisms and feedback control systems. Intended for use in conjunction with any standard text in the field, the manual is designed for courses in both industry and school and stresses the practical application of principles while theoretical material is kept to a minimum.

*Contents:* (1) Introduction. (2) Description of the Basic System. (3) Characteristics of Feedback in Control Systems. (4) Effect of Various Input Signals. (5) Measurement of Transducer Characteristics. (6) Characteristics of the Single Loop System. (7) Introduction of the Tachometer. (8) Performance of the Closed Loop System. (9) Analysis & Laboratory Test of a Basic Servomechanism. Appendix: Symbols & Definitions.

## DICTIONARIES

**Glossary of Soviet Military Terminology; English-Russian, Russian-English.** (U.S., Dept. of the Army, Technical Manual TM 30-544.) Washington, Superintendent of Documents, May, 1955. 802 pp. $2.00.

## DRAFTING

**Drafting Standards, Aluminum Extruded and Tubular Products.** 3rd Ed. New York, Aluminum Extruded Products Division, Aluminum Association, May, 1957. 99 pp., diagrs., tables.

The purpose of this manual is to outline certain basic practices that are necessary with extruded products and to standardize those practices insofar as seems practical. Many of the tolerance tables in Section VII have been rearranged, and new tolerance tables have been added. A new section of mathematical tables and formulas has been added which contains several pages of formulas and tabular data commonly used in calculating cross-sectional areas. It also includes five-place tables of trigonometric functions for all angles from 0 to 90°.

## ELECTRICITY

**Aluminum in Electrical Engineering;** An Introductory Survey. London, The Aluminum Development Association, May, 1957. 72 pp., illus., tables. 4*s.* 6*d.*

A review of the electrical properties of aluminum, showing the range of its existing applications and its potentialities. Technical aspects are discussed only briefly but include the principles underlying the many connection methods that are now being developed. The brochure is addressed primarily to engineers, designers, equipment manufacturers, and electrical contractors.

## GEOPHYSICS

**Advances in Geophysics, Vols. 2 & 3.** Edited by H. E. Landsberg. New York, Academic Press, Inc., 1955-1956. Vol. 2, 286 pp., illus., diagrs., tables, $7.50. Vol. 3, 378 pp., illus., diagrs., tables, $8.80.

*Contents: Vol. 2:* Advances in Radar Weather, J. S. Marshall, Walter Hitschfeld, and K. L. S. Gunn. Methods of Objective Weather Forecasting, Irving I. Gringorten. Wind Generated Gravity Waves, Willard J. Pierson, Jr. Geological Chronometry by Radioactive Methods, J. Laurence Kulp. Earthquake Seismographs and Associated Instruments, Hugo Benioff.

*Vol. 3:* Arctic Ice Island Research, A. P. Crary. Recent Developments in the Study of the Polarization of Sky Light, Zdenek Sekera. Subcontinental Structure in the Light of Seismological Evidence, Perry Byerly. Heat Flow through the Deep Sea Floor, E. C. Bullard, A. E. Maxwell, and R. Revelle. The Interior of the Earth, J. A. Jacobs. Subsurface Geophysical Methods in Ground-Water Hydrology, P. H. Jones and H. E. Skibitzke. Geophysical Research with Artificial Earth Satellites, S. F. Singer.

## MATERIALS

**The Science of Engineering Materials.** Edited by J. E. Goldman. New York, John Wiley & Sons, Inc., 1957. 528 pp., illus., diagrs., tables. $12.

The papers presented in this volume were originally delivered as lectures on the impact of

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solid-state science on engineering materials at the Carnegie Institute of Technology in June, 1954, by 15 leading research scientists. The term solid state has been employed rather broadly; thus the book includes chapters on such important engineering materials as cements, polymers, and glasses which may not represent an equilibrium state, are not solid in the conventional sense, and the study of which has emerged as a science only in the last few years. Nevertheless, this work will serve to introduce engineering educators and students alike to at least some of the intricacies of these and other materials and the concepts involved in solid-state science.

*Contents: Part 1, The Structure of Matter.* (1) Applications of Solid-State Science in Engineering: An Introductory Survey, H. Brooks. (2) Structure of Atoms and Atomic Aggregates, J. Bardeen, W. Bitler, and J. E. Goldman. (3) Accomplishments and Limitations of Solid-State Theory, H. Brooks. (4) Crystal Imperfections, J. Bardeen. *Part 2, Metals and Alloys.* (5) The Metallic State; Theory of Some Properties of Metals and Alloys, R. Smoluchowski. (6) Electron Theory of Alloy Formation and Elastic Properties, H. Jones. (7) Dislocations in Solids, R. Smoluchowski. (8) Dislocation Theories of Mechanical Properties, H. W. Paxton. (9) Experimental Evidence for Behavior of Dislocations, E. R. Parker. (10) Phase Transformations in Metals and Their Influence on Mechanical Properties, T. A. Read. *Part 3, Surfaces.* (11) Surface Phenomena, R. Gomer. *Part 4, Magnetism and Magnetic Properties.* (12) The Theoretical Basis of Magnetic Phenomena, J. E. Goldman. (13) The Physics of Magnetic Materials, R. M. Bozorth. *Part 5, Semiconductors and Dielectrics.* (14) The Physics of Semiconductors, K. Lark-Horovitz and V. A. Johnson. (15) Semiconductor Devices, E. M. Conwell and W. J. Leivo. *Part 6, Non-Crystalline Materials.* (16) Some Aspects of the Physics and Chemistry of Cement, S. Brunauer. (17) Molecular Structure and Mechanical Behavior of High Polymers, T. Alfrey, Jr. (18) The Physics of Glass, T. H. Davies. Name Index. Subject Index.

**Probleme der Plastizitätstheorie (Problems in the Theory of Plasticity).** William Prager. Basel, Verlag Birkhauser, 1955. 100 pp., figs. 12.50 Sw. fr. In German.

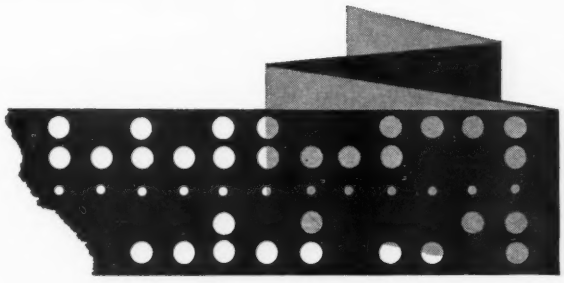
This book is based on a series of lectures given by the author at the Federal Polytechnic Institute (ETH) in Zurich during November and December, 1954. Since it is limited to selected problems in the theory of ideally plastic materials, the author has been able to bring the reader abreast of current research without presupposing previous knowledge of the theory of plasticity. Most of the problems can be found in the technical literature of recent years and appear in book form for the first time. The text aims mainly to arouse in the reader an intuitive understanding of the peculiarities of plastic behavior. The numerous literature references afford the reader the possibility of deepening this understanding by further study.

*Contents:* (1) The Mechanical Behavior of Plastic Solids. (2) The Mechanical Behavior of Plastic Structures. (3) The Limit Load Method. (4) Finite Plastic Deformations.

## MATHEMATICS

**Selected Papers in Statistics and Probability by Abraham Wald.** Edited for the Institute of Mathematical Statistics. Stanford, Calif., Stanford University Press, 1957. 702 pp., illus., tables. $10.

Practically all of Wald's contributions to statistics are contained in this volume which was first published in 1955 by McGraw-Hill Book Company, Inc., and is now being reissued by Stanford University Press. The Committee on the Wald Memorial Volume at Stanford selected 52 papers from various periodicals and publications which represent his original contributions to decision function theory, sequential analysis, probability, nonparametric inference, the Neyman-Pearson system of statistical inference, the theory of re-

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gression, analysis of variance, and other related topics. In the introduction an evaluation is given of his work, its relation to the work of others in the field, and the relation of the different papers to each other. One of these papers, reprinted from *Annals of Mathematical Statistics*, 1952, contains a bibliography of Wald's works published up to that time.

The book was edited for the Institute of Mathematical Statistics by T. W. Anderson, H. Cramér, H. A. Freeman, J. L. Hodges, Jr., E. L. Lehman, A. M. Mood, and C. M. Stein.

**Vorlesungen über partielle Differentialgleichungen (Lectures on Partial Differential Equations).** I. G. Petrowski. Translated from the Russian by Viktor Ziegler. Leipzig, B. G. Teubner Verlagsgesellschaft, 1955. 296 pp., figs. DM 17.–; $4.20. In German.

This collection of lectures given at the Moscow State University has been translated from the second Russian edition (Moscow, 1952). It deals chiefly with partial differential equations of the second order with one unknown, such as the heat conduction and wave equations, and the Laplace differential equation. The author gives many examples that show the application of these equations to physical problems.

*Contents:* (1) Introduction, Classification of Equations. (2) Hyperbolic Differential Equations: Cauchy's Problem in the Field of Non-analytic Functions, Oscillations of Finite Bodies. (3) Elliptic Differential Equations. (4) Parabolic Differential Equations. Appendix: The Solution of the First Boundary Value Problem for the Heat Conduction Equation According to the Lattice Point Method, Remarks on the Lattice Point Method.

**Vorlesungen über die Theorie der gewöhnlichen Differentialgleichungen (Lectures on the Theory of Ordinary Differential Equations).** I. G. Petrowski. Translated from the Russian by Viktor Ziegler. Leipzig, B. G. Teubner Verlagsgesellschaft, 1954. 198 pp., figs. DM 7.80; $1.87. In German.

This translation of the fourth edition, published in Moscow in 1952, is a development of lectures first delivered in 1936–1937 at the State Universities of Saratov and Moscow. Many examples drawn from the fields of physics and mechanics are included, as well as problems for the student.

*Contents:* A Differential Equation of the First Order with One Unknown Function: General Concepts, The Simplest Differential Equations, General Theory. Systems of Ordinary Differential Equations: General Theory, General Theory of Linear Systems, Systems of Linear Differential Equations with Constant Coefficients. Partial Differential Equations of the First Order with One Unknown Function.

**Technical Descriptive Geometry.** B. Leighton Wellman. 2nd Ed. New York, McGraw-Hill Book Company, Inc., 1957. 628 pp., diagrs. $5.75.

Beginning with the most elementary concepts and progressing by easy stages to complex intersection and development problems, this treatment of descriptive geometry for students and industrial draftsmen contains an improved presentation of visibility, perpendicular lines, views of a circle, and cylinder intersections. In addition to many new illustrations, the second edition contains two new chapters on vector applications and geology and mining applications.

The author is Professor of Mechanical Engineering and Head, Division of Engineering Drawing, Worcester Polytechnic Institute.

## MISSILES

**Guided Weapons.** Eric Burgess. New York, The Macmillan Company, 1957. 255 pp., illus., diagrs., tables. $5.00.

With the limitation that it must be accepted that a modern guided weapon could never be designed from unclassified material, Mr. Burgess, a well-known lecturer and writer, introduces the reader to the historical and technical fundamentals on which guided weapons are based. The descriptions of short-range, intermediate, and in-

tercontinental ballistics missiles include their distinguishing characteristics, manner of operation, and their capability of carrying nuclear warheads. Each type of missile is classified according to use: ground-to-air, air-to-air, and ground-to-ground. To make the book useful as a reference to both the engineer and the layman, each category of missile is treated in a separate chapter which enumerates such technical features as the guidance system, the power plant, the propellant used, and the expected lethal effectiveness.

A short bibliography is appended to the text which includes references to guided and unguided missiles, propulsion, instrumentation, high-speed flight, and materials.

### NUCLEAR ENERGY

**Corrosion and Wear Handbook for Water Cooled Reactors.** Edited by D. J. DePaul. Sponsored by Naval Reactors Branch, Division of Reactor Development, U.S. Atomic Energy Commission. (TID 7006/March 57.) Washington, Superintendent of Documents, 1957. 293 pp., illus., diagrs., tables. $2.25.

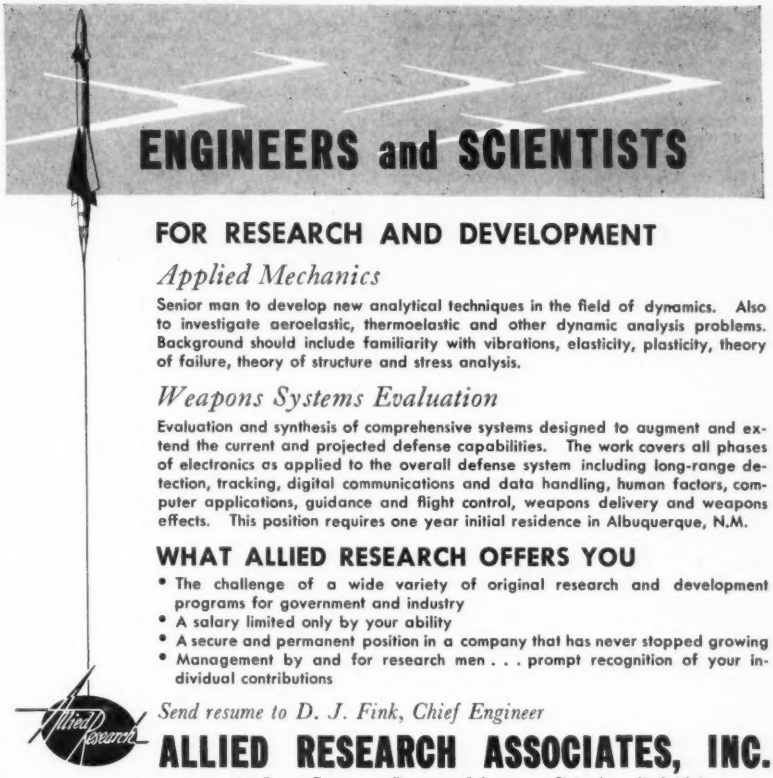
The sixth in a series on basic reactor technology devoted to problems resulting from the use of water as a heat-transfer medium in a reactor plant. The book is organized into three parts: *Part A* states the problems associated with the use of high-purity, high-temperature water as a reactor coolant and discusses the selection of reactor materials, the fundamental facts of corrosion, friction and wear, and water technology; *Part B* gives basic reference data for use in design work. Corrosion and wear properties of various materials and combinations of materials under specified conditions are stated, plus the effect of variable factors on corrosion and wear and recommended testing procedures; *Part C* deals with such special problems as crevice, stress, and intergranular corrosion, and with application and manufacturing problems involving wear. The handbook supplies theory, as well as experimental data, and is written for those engaged in nuclear reactor work who may wish to use the findings in additional research and development. Included also are corrosion and wear data resulting from the development of the "Nautilus" submarine reactor and the Shippingport Pressurized Water Reactor (PWR) projects.

### PHOTOGRAPHY

**Proceedings of the Third International Congress on High-Speed Photography.** Held under the Auspices of the Department of Scientific and Industrial Research in London, September 10–15, 1956. Edited by R. B. Collins. London, Butterworths Scientific Publications; New York, Academic Press Inc., 1957. 417 pp., diagrs., illus., tables. $13.

The range of topics discussed at the Third International Congress indicates the growing importance of high-speed photography to scientific investigation. Apart from entirely new and original techniques, many improved embodiments of existing techniques were reported by representatives from such countries as France, Germany, Switzerland, the Netherlands, Japan, the Soviet Union, Great Britain, and the United States. The agenda of the Congress included papers on flash light sources, medium repetition rate cameras, mechanical optical drum cameras, inertialess shutters, stereoscopic techniques, image-splitting and image-sampling techniques, photographic materials, X-rays, and film evaluation, as well as other uses and techniques of scientific cinematography.

*Partial Contents: Part 6—Application to Ballistics and Explosives:* Ignition of Gaseous Mixtures in a Shock Tube, M. Giltaire. Comparative Investigations into the Reaction Mechanisms of Permitted Explosives Based on Rotating Film Records of their Explosion Flames, A. Berthmann and H. Kaufer. Photography in Guided Weapon Trials, P. B. N. Nuttall-Smith. Applications of High-Speed Photographic Techniques to Hyper-Velocity Free-Flight Investigations, J. S. Rinehart. *Part 7—Instrument Aids:* Chronograph for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## PHYSICS

**The Defect Solid State.** T. J. Gray, D. E. Rase, R. R. West, D. P. Detwiler, W. G. Lawrence, and T. J. Jennings. New York, Interscience Publishers, Inc., 1957. 511 pp., diagrs., tables. $11.

The particular aim of this publication is to focus attention on the relationship between the defect nature of solids and the various physical and chemical properties which they exhibit. The contributors are all affiliated with the College of Ceramics at Alfred University, State University of New York.

*Contents:* (1) Defect Nature of Solids, T. J. Gray. (2) Semiconductivity and Associated Phenomena, T. J. Gray. (3) Certain Theoretical Aspects of Semiconductivity, D. P. Detwiler. (4) Diffusion in Ionic Lattices, Sintering, and Reactions in the Solid State, T. J. Gray. (5) Corrosion Processes, T. J. Gray. (6) The Magnetic Properties of Solids, T. J. Gray. (7) Defect Structure and Catalysis, T. J. Gray. (8) Dielectric Materials, D. P. Detwiler. (9) Phase Equilibria, D. E. Rase. (10) Ceramic Materials for High Temperatures, W. G. Lawrence. (11) Intermetallic Compounds, D. P. Detwiler. (12) Experimental Techniques, R. R. West and T. J. Jennings. Author Index. Subject Index.

## RESEARCH LABORATORIES

**Thermodynamics Laboratories at the United States Air Force Academy.** P. H. Dane and E. F. Obert. (Presented at the Annual Meeting of the American Society for Engineering Education, Cornell University, June, 1957.) Evanston, Ill., 1957. 11 pp., diagrs.

A description of the actual facilities planned and designed for the Thermodynamics Laboratory at the U.S. Air Force Academy in Colorado Springs, Colo. It includes an outline of the mission of the Academy, its general philosophy of operation, and the methods of instruction.

## SPACE TRAVEL

**Proceedings of the American Astronautical Society, 3rd Annual Meeting, December 6-7, 1956, New York.** New York, The Society, 1957. 177 pp., illus., diagrs., tables.

This volume contains the full text of the 18 technical papers presented at the meeting. The papers relate to four broad topics: Space Flight Mechanics, Satellite Research and Application, Space Medicine, and Relativity and Gravitational Research.

*Contents:* Education in the Astronautical Sciences, Charles S. Draper. The Satellite and Meteorology, Harry Wexler. Space Exploration—The New Challenge to the Electronics Industry, Henry E. Prew. Orbit Lifetimes of Earth Satellites, Harold B. Ketchum. The Problems of Goddard and Related Problems of Rocket Flight, Frank Faulkner. Radio Tracking of IGY Satellite, Roger L. Easton. Meteoric Abrasion Studies Proposed for Vanguard, M. J. Swetnick. Cosmic Ray Instrumentation for the IGY Program, Robert C. Haymes. What the Future Holds for the Earth Satellite, R. P. Haviland. Long Term Human Confinement in Space Equivalent Vehicles, Charles Dempsey, Franklin D. Van Wart, John H. Duddy, and Jack Hockenberry. Accelerative Forces Associated with Leaving and Re-Entering the Earth's Gravitational Field, Rufas R. Hessberg, Jr. Mechanoreceptors, Gravireceptors, Hubertus Strughold. Plants as a Means of Balancing a Closed Ecological System, James G. Gaume. Environmental Problems Connected with Space Ship Occupancy, William T. Ingram. Space Vehicles as Tools for Research in Relativity, S. Fred Singer. Experimental Aspects of General Relativity Theory, Lou Witten. Survey of Relativity, Peter Bergmann. Principal Directions in Current Research on Gravitation, Bryce DeWitt. Project Moon Watch—Optical Tracking of IGY Satellite, Armand N. Spitz.

## STRUCTURES

**The Analysis of Structures,** Based on the Minimal Principles and the Principle of Virtual Displacements. Nicholas John Hoff. New York, John Wiley & Sons, Inc., 1956. 493 pp., diagrs., tables. $9.50.

Proceeding from the premise that the student of engineering, in studying the analysis of structures, need not memorize a single formula if the fundamental principles are understood, every method presented in this book is an almost obvious consequence of the basic principles and can be derived with a minimum amount of mathematical manipulation.

In his presentation of structural analysis as a logical and unified theory based on a small number of first assumptions, Dr. Hoff first develops the principle of virtual displacements. This is followed by a discussion of the minimal principles of structural theory with which all practicing engineers must be familiar. The final chapters are devoted to the calculation of buckling loads and to complementary energy and least-work methods. The book is a consolidation of lecture notes prepared for a first-year graduate course given to students of aeronautical, civil, and mechanical engineering, and of applied mechanics, and assumes that the reader has had sufficient training in engineering to comprehend the mathematics and mechanics involved in such a study. Whenever mathematical methods beyond the elementary principles of the calculus are used they are explained in the text.

The author, formerly Head, Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn, is now Head, Department of Aeronautical Engineering, Stanford University.

## THERMODYNAMICS

**Elementary Thermodynamics.** Virgil Moring Faires. 3rd Ed. New York, The Macmillan Company, 1957. 379 pp., illus., diagrs., tables. $6.75.

Extracted from the author's larger work, *Thermodynamics*, this edition is intended for short theoretical courses. Employing basic principles, the text presents a study of the theory of internal combustion engines, gas turbines, air compressors, steam turbines, refrigeration, air conditioning, and topics of related interest such as the flow of fluids and heat transfer. For the most part, the presentation of theory is followed with an application to actual engineering situations. The author, Professor of Mechanical Engineering, North Carolina State College, has supplied a bibliography of 160 items and an appendix that includes the problems for each of the chapters.


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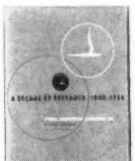

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**Liquid Oxygen Check Valve.** Provides "zero" leakage at low back pressures and high shock resistance; built to survive heavy cycling loads. *Bobrick Mfg. Corp.*, 1839 Blake Ave., Dept. A-1, Los Angeles 39, Calif.

**Three-Dimensional Flight Instrument.** A miniature replica of the aircraft gives the pilot three-dimensional orientation of his airplane with respect to the ground by moving about the three principal axes directly with the aircraft; this replica is designed for free universal movement, with respect to, and within, a gyroscopically stabilized globe representing the horizon by which the aircraft's heading also is represented. *Mr. Raoul Castro*, P.O. Box 56, Brookfield, Ill.

**NCCS-4 Camera Control Systems.** Automatically adjusts the cameras for flight variables such as altitude, speed, and light conditions; gives the pilot a view of his photographic targets. *Chicago Aerial Industries, Inc.*, 1980 Hawthorne Ave., Melrose Park, Ill.

**High-Energy Silver-Zinc Batteries for Missiles, Drones, & Aircraft.** Self-activating (one-shot) and rechargeable units; 0.2- to 0.8-sec. activation; fractional to 1,000 amp.; voltages to 500 volts. *Frank R. Cook Co.*, 36 S. Santa Fe Dr., Denver 23, Colo.

**"Dynisco" Miniature High Output Pressure Pickup.** Total weight of these flange-mounted units is 7 gm.; output varies from 25 to 100 millivolts full scale, depending on the pressure range. *Dynamic Instrument Co.*, 28 Carleton St., Cambridge 42, Mass.

**Model PT45 Pressure Transducer.** Incorporates compensation for sensitivity, zero balance, zero drift, and sensitivity change due to temperature, input impedance, and output impedance. *Dynamic Instrument Co.*, 28 Carleton St., Cambridge 42, Mass.

**"Instalite" Automatic Jet-Engine Reigniter.** Designed to eliminate engine flameout; this little platinum-alloy rod relights fuel flow automatically and instantaneously. *Charles Engelhard, Inc.*, 850 Passaic Ave., E. Newark, N.J.

**Immersible Plug-Type Fuel Valve.** Mounts inside integral wing fuel cell on inside wall of wing spar with motor or manual actuator extending through spar and outside of tank; permits routing of all fuel lines inside fuel cells, emerging only for delivery to engines. *General Controls Co.*, 801 Allen Ave., Glendale 1, Calif.

**Fabric-Reinforced Silicone Rubber Hose.** Capable of handling concentrated hydrogen peroxide. *Hewitt-Robins Inc.*, Stamford, Conn.

**Portable, Fully Transistorized Infrared Radiometer.** Designed for automatic infrared measurements of a 360-deg. radiation pattern of jet aircraft "in-flight" operation. *Hoffman Electronics Corp.*, 3761 S. Hill St., Los Angeles 7, Calif.

**Model RG-15-0102-1 Rate Gyro.** Hermetically sealed in a dry helium-filled steel case. *Humphrey Inc.*, 2805 Canon St., San Diego 6, Calif.

**"Hydromat" Multiple-Input Flight Control Servovalve.** Designed for control of a tandem hydraulic cylinder; mechanical signals created by the pilot, as well as electric control signals created by electronic amplifiers. *Hydraulic Research & Mfg. Co.*, 2835 N. Naomi, Burbank, Calif.

**#1701 Series Hydraulic Control Valves.** These motor-operated units provide shock-free directional flow control. *Lyndon Aircraft, Inc.*, 140-1 Clifford St., Newark, N.J.

**Rotary Actuator.** Permits flight load "feel" during automatic or manual piloting. *Lyndon Aircraft, Inc.*, 140-1 Clifford St., Newark, N.J.

**Relief Valves for Air-Borne Applications.** For pressures from 1 to 6,000 psi. *M. C. Mfg. Co.*, Lake Orion, Mich.

**Miniaturized Magnetic Amplifier for Hydraulic Valves.** Features high gain and fast response; suitable for controlling low power output devices such as hydraulic servovalves. *Magnetic Amplifiers, Inc.*, 632 Tinton Ave., New York 55, N.Y.

**Subminiature Linear-Stroke Solenoid.** For applications in instrumentation and missile control; weighs less than an ounce; dimensions are 0.672 by 0.622 by 0.622 in. *J. A. Maurer, Inc.*, 37-01 31st St., Long Island City, N.Y.

**Explosive Ordnance Products.** Condensed data bulletin CD-1-57 describes electric primers, squibs, and igniters, explosive bolts, Cad cartridges, gas generators, power packs, ejectors, and high-pressure, hermetically sealed terminals. *McCormick Selph Associates*, Hollister Airport, Hollister, Calif.

**Background Music System for Jet Transports.** Approximately half the size and weight of equipment now in use. *Muzak Corp.*, Muzak Bldg., 229 4th Ave., New York 3, N.Y.

**10 GPM Overcenter Variable Delivery Hydraulic Pump.** Features 2.8 hp./lb. ratio; delivers over 50 hydraulic horsepower in an envelope 9 1/8 by 6 1/4 in. weighing approximately 19 lbs. *The New York Air Brake Co.*, Stratopower Div., Starbuck Ave., Watertown, N.Y.

**Water-Cooled Pressure Pickup.** This high-temperature transducer is designed for use in rocket and jet engines; can withstand gas temperatures above 5,000°F. *Norwood Controls, Unit-Detroit Controls Corp.*, Norwood Mass.

**1-Oz. Quick-Disconnect for Aircraft Control Cable.** Small diameter makes it possible to use this disconnect in extremely tight quarters. *Pacific Scientific Co.*, 1430 Grande Vista Ave., Los Angeles 23, Calif.

**Miniature Pneumatic Pressure Reducer.** Reduces pressure from 3,000 psi; weighs from 0.17 to 0.25 lb. *Pneu-Hydro Valve Corp.*, 364 Glenwood Ave., E. Orange, N.J.

**Back-Up Rings of Teflon.** Used in conjunction with O-ring seals in hydraulic and similar pressure systems. *Sparta Mfg. Co.*, Dover, Ohio.

**Aircraft Bolts With "Nylok" Locking Insert.** 16-page bulletin describes company's complete line of standard and special aircraft bolts. *Standard Pressed Steel Co.*, Box 869, Jenkintown, Pa.

**High-Strength Aircraft Fasteners.** For air-frame and engine use; 4-page folder reviews company's complete line. *Standard Pressed Steel Co.*, Box 869, Jenkintown, Pa.

**Lightweight Self-Locking Nuts.** Claimed to be 49 per cent lighter than their standard counterparts without sacrificing fastening strength. *Standard Pressed Steel Co.*, Box 869, Jenkintown, Pa.

**Transistor Inverter for Missile and Aircraft Application.** Designed to operate gyros, hysteresis motors, strain gages, and other air-borne equipment where precision 400 cps power is necessary. *Varo Mfg. Co., Inc.*, 2201 Walnut St., Garland, Tex.

**Oil-Cooled Motorpump.** For turbine-powered air transports; said to offer weight-saving of approximately 25 per cent over the conventional air-cooled motorpump. *Vickers Incorporated*, Detroit 32, Mich.

**Model W-33-7511 24-Hour, 8-Day Panel Clock.** Mounted in a lightweight black oxidized aluminum case with a 1 7/8 in. dial opening. *Wakmann Watch Co., Inc.*, 15 W. 47th St., New York, N.Y.

**"Rotomite" Swivel Fittings for Aircraft Piping Systems.** 22-page engineering bulletin AM-11. *The Weatherhead Co.*, Aviation Div., 300 E. 131st St., Cleveland, Ohio.

**Aircraft Instruments.** 44-page catalog features Weston's line of flight instruments, trim tab indicators, aircraft voltage, current and temperature measurement units. *Weston Electrical Instrument Corp.*, Newark 12, N.J.

## ELECTRONIC & ELECTRICAL EQUIPMENT

**"S-20" Shell Enclosed Miniature Rectangular Connectors.** A positive self-polarizing, aluminum die cast shell completely surrounds the plug pins, protecting them from accidental damage or short circuit in the unmated position. *Anton Electronic Laboratories Inc.*, 1226 Flushing Ave., Brooklyn 37, N.Y.

**Miniature Electrical Connectors.** Bulletin 4003 describes units for extreme environmental applications. *Consolidated Electrodynamics Corp.*, Glendale Div., 740 Salem St., Glendale 3, Calif.

**Potentiometer Model Selector.** 8 3/4-in. plastic-coated circular chart has inner rotating wheel that visualizes specifications of company's complete line of potentiometers. *DeJur-Amsco Corp.*, 45-01 Northern Blvd., Long Island City 1, N.Y.

**Subminiature Connectors.** 12-page brochure gives complete data on Continental connectors. *DeJur-Amsco Corp.*, Electronic Sales Div., 45-01 Northern Blvd., Long Island City 1, N.Y.

**Series 500 High-Speed Sampling Switches.** Up to three poles with 60 shorting channels or 30 nonshorting channels per pole; special construction affords replacement of all brushes without force or phase adjustments. *General Devices, Inc.*, P.O. Box 253, Princeton, N.J.

**D.C. Miniature Motors.** 10-page catalog describes permanent magnet and wound field motors and related parts. *Globe Industries, Inc.*, 1784 Stanley Ave., Dayton 4, Ohio.

**Model TD-812A Hermetically Sealed Overvoltage Relay.** For high-speed, high-altitude aircraft; insensitivity to high-frequency vibrations in the order of 10g to 500 cps is claimed. *Hartman Electrical Mfg. Co.*, 175 N. Diamond St., Mansfield, Ohio.

**Hermetic Seal AN Connectors.** 16-page catalog No. 657C covers a wide range of shell sizes and insert configurations for aircraft, communications, electronic controls, and instrument applications. *Hermetic Seal Corp.*, 29 S. 6th St., Newark 7, N.J.

**"HZPR" Series 10-Watt Voltage Regulator Diodes.** Incorporate a large area diffused junction offering extremely low dynamic impedance; suited to transistor and mag-amp circuitry. *Hoffman Semiconductor Div.*, Hoffman Electronics Corp., 930 Pitner Ave., Evanston, Ill.

**OS-45 Chemical Coolant-Dielectric.** For air-borne electronic equipment; remains pumpable at temperatures ranging from −65° to 400°F. *Monsanto Chemical Co.*, Organic Chemicals Div., 800 N. 12th Blvd., St. Louis 1 Mo.

**High-Torque Low-Watts Synchronous Motor.** Type 18-A-8125-01 runs at 12,000 r.p.m. and has 0.85 oz.in. pull-out torque with 20-watt power consumption. *John Oster Mfg. Co.*, Avionic Div., Racine, Wis.

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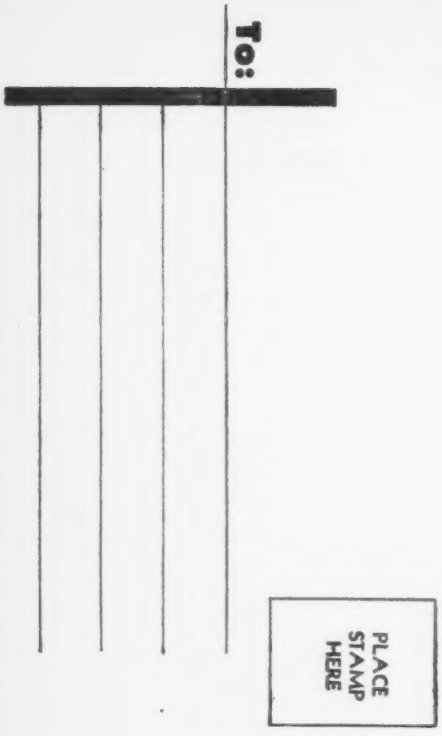



**Low-Drive Ferrite Core.** For use as an information-storing device in electronic digital computers; can withstand large disturbing current impulses without reversing its flux state. *Radio Corp. of America*, RCA Bldg., 30 Rockefeller Plaza, New York 20, N.Y.

**Type 47 Subminiature Relay.** Will provide continuous duty to 200°C. and intermittent duty to 250°C.; coil assembly is hermetically isolated from the contact assembly. *Reltron Corp.*, 282 Centre St., Newton 58, Mass.

**Power Supply Unit for 120-Ohm Strain-Gage Bridge.** Filtered and regulated by transistors. *Spar Engineering & Development, Inc.*, Paxson & South Aves., Wyncote, Pa.

**Hermetically Sealed, High-Temperature Sine Switch.** Designed to operate continuously at temperatures as high as 375°F. *Spencer Thermostat Div.*, Metals & Controls Corp., Attleboro, Mass.

**High-Frequency Variable Transformers.** 28-page bulletin P257H offers features, ratings, and complete data on "Powerstat" units. *The Superior Electric Co.*, Dept. 257, 83 Laurel St., Bristol, Conn.

**"Tape Cable" Electrical Cable in Tape Form.** A flat, multiconductor, ribbon-like cable; features minimum cross-sectional area, minimum interconductor capacitance, high tear strength, high flex life, and resistance to chemical attack. *Tape Cable Corp.*, 790 Linden Ave., Rochester 10, N.Y.

**"Rayonic" Type 3 AHP Cathode-Ray Tube.** Designed to give maximum emphasis to brightness and definition; small size and high performance permit use where space is limited. *Waterman Products Co., Inc.*, 2445 Emerald St., Philadelphia 25, Pa.

## DRAFTING ROOM, PRODUCTION, & MISC. EQUIPMENT

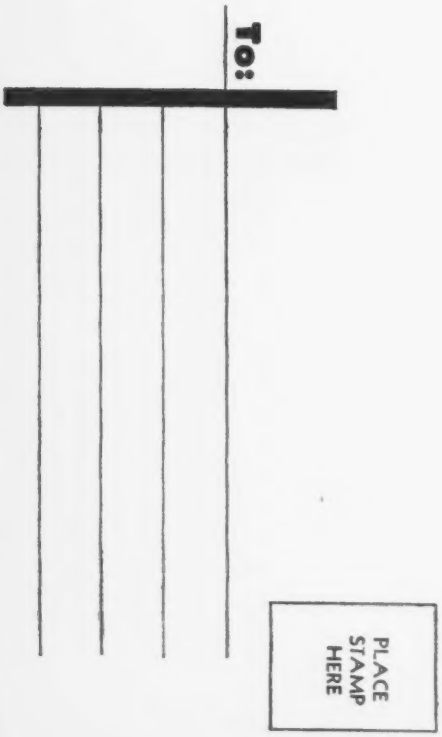
**Large-Size Acrylic Plastic Drafting Triangles.** These transparent instruments are available up to 24 in. in size from stock, and larger sizes on special order. *Dolgorukov Mfg. Co.*, 407 Fisher Bldg., Detroit 2, Mich.

**#3 FCT Lock Clamp.** For any machine or fixture with "T" slot; allows operator to clamp quickly any shape or thickness from 0 to 3 in. with no adjustment needed. *General Alliance Corp.*, 2105 Moore St., San Diego 1, Calif.

**Manually Operated Tubing Tools.** For fabricating aircraft-grade stainless steel tubing; catalog No. 3066 includes data on tube flaring, bending, cutting, deburring, and double flaring tools, as well as test plugs. *The Imperial Brass Mfg. Co.*, 1200 W. Harrison St., Chicago 7, Ill.

**Optical Tooling.** 56-page manual covers the basic principles and illustrates the major instruments and accessories used in this field. *Keuffel & Esser Co.*, Hoboken, N.J.

**Molten Salt Bath Cleaning & Descaling Process.** For aircraft parts' reconditioning and overhaul; quickly removes scale, oxides, combustion deposits, and other surface contaminants. *Kolene Corp.*, 12890 Westwood Ave., Detroit 23, Mich.




## RESEARCH & TEST EQUIPMENT

**"Magnetic Tape Instrumentation."** 16-page brochure describes the use of magnetic tape for recording scientific research and industrial process data. *Ampex Corp.*, 934 Charter St., Redwood City, Calif.

**"Time Interval Measurements and How to Make Them."** Data file 112 contains diagrams, photos, and schematics describing techniques for using time interval meters. *Beckman/Berkeley Div.*, Dept. 733, 2200 Wright Ave., Richmond, Calif.

**Ballistic Film Analyzers.** Bulletin No. CR-191 describes machines used by data reduction facilities to measure linear distances or angles on photographic film or plates. *Coleman Engineering Co., Inc.*, 6040 W. Jefferson Blvd., Los Angeles 16, Calif.

**High-Temperature Strain Gage.** For measurements up to 1,100°F.; strain sensitive element is Karma wire; nominal resistance is 120 ohms; gage factor is 2.25. *Columbia Research Laboratories*, MacDade Blvd. & Bullens Lane, Woodlyn, Pa.

**Crash-Resistant Oscillograph Record Magazine.** For flight-test recording; will withstand a 400g shock and a 2,000°F fire. *Consolidated Electrodynamics Corp.*, 300 N. Sierra Madre Villa, Pasadena, Calif.

**70 mm. Missile Tracking Camera.** Larger film size permits use of greater focal lengths for greater magnification. *Flight Research, Inc.*, Richmond, Va.

**Hydraulic Accessories Test Machine.** Designed for functional and operational testing of all types and sizes of aircraft and industrial hydraulic components. *Greer Hydraulics, Inc.*, Test Equipment Div., New York International Airport, Jamaica 30, N.Y.

**Demonstration Model Wind Tunnel.** This tunnel is entirely portable; on permanent casters; approximately 10 ft. long and 6 ft. in height; octagonal test section of 7 by 10 in. is provided in which speeds up to 200 knots can be obtained with a 5 hp. motor. *West Coast Research Co.*, 2371½ Westwood Blvd., Los Angeles 64, Calif.

# Timesaver + Spacesaver = LIFESAVER

Keeping pace with the development of modern, high-performance fighter aircraft, Wright Air Development Center has created a whole new concept in instrumentation.

Old fashioned clock-type dials which take time to read and interpret, and which waste valuable space, are being replaced by what WADC calls "whole panel instrumentation." This concept presents flight information in a relatively few, integrated displays in directly usable form, saving time and space. And, it is now possible to place command information before the pilot, showing him what he should be doing and how to do it.

Servomechanisms, Inc. is proud to cooperate with WADC and Air Materiel Command in applying its proven design experience to the development of several of the new whole panel instruments. One, for example, provides extremely accurate altitude and rate-of-climb information on vertical scales, thereby relating information to a common horizontal line—a reference integrated with companion instruments. For additional data, write to:

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# ASW EQUIPMENT
## *BY STRATOS*

- Sonobuoy Launchers
- Retro Ejectors
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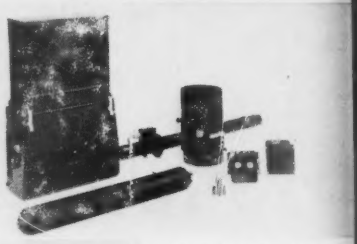
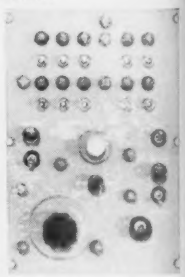


Retro Marine Marker Ejector System, Control Box, 3000 psi Compressor, Solenoid Valve, High Pressure Storage Bottle.



Master Control Panel to control complete ASW stores ejection system.

Stratos builds a variety of equipment and complete pneumatic systems for sub-hunting patrol aircraft. Included are:

Free Piston Pneumatic Store Ejectors—using the patented "Pogo Stick" principle to hurl delicate sonobuoys clear of the aircraft without endangering delicate components:

Complete ejection systems to plant flares and markers with pinpoint accuracy, using an air gun to "shoot" stores rearward at a speed which cancels out the aircraft's forward motion; and,

Associated equipment such as skin door actuators, compressors, valves and integrated control systems.

Sonobuoy ejector using "Pogo Stick" Free Piston Actuator principle.

Pneumatic Actuator for opening skin door.

**STRATOS**

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